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Preface: Cumulative Index

Thirty-seven years ago, Thomas J. Watson, Jr., introduced the first issue of the *IBM Journal of Research and Development* with the following message:

The new IBM Journal of Research and Development *is a strong indication of the increasing emphasis we at IBM want to place in the future on fundamental science and technology.*

In the IBM Journal, *our scientists and engineers will describe their latest and most significant new ideas and concepts, as well as new and improved products. I hope and believe that the IBM Corporation will make real contributions to the expanding perimeters of knowledge in the physical sciences and mathematics, as well as in the more specialized areas of data processing, computer technology, and communications. The prompt publication of new scientific and technological advances is, I believe, of real benefit to the individual and to the company. I also feel that it is desirable to share such knowledge with others throughout the world as soon as is reasonably possible.*

New scientific knowledge is, without doubt, one of the greatest sources of hope for man in our time. It can never remain the exclusive secret of any group or nation for any considerable period. I am convinced that, through a more widespread and rapid publication of any additions we may make to this store of knowledge, we at IBM can contribute significantly to a freer exchange of ideas and knowledge among all men.

Since its creation in 1957, the *IBM Journal of Research and Development* has reflected the company's technical emphasis by publishing 2190 papers and communications and by listing more than 20 000 U.S. patents issued to IBM and more than 30 000 papers published by IBM authors in other technical journals.

This issue is a thirty-seven-year Cumulative Index covering the 203 issues of the *Journal* published to date. The Index consists of four parts: authors, topics, subjects, and abstracts.

Author Index Entries in the Author Index are arranged alphabetically by the last name of the first author. Primary entries contain the author names, the title of the paper, the volume and issue number in boldface, the beginning page number, and the year of publication.

If a paper has more than one author, secondary entries appear for the additional authors. These entries refer to the primary entry and omit the other authors and the title.

Topic Index The Topic Index identifies those journal issues which are devoted in whole or in part to a particular topic. Papers belonging to these topics are listed in order of publication. Listings include the title of the paper, the last name of the first author, and the beginning page number. Headings include the volume and issue number and the year of publication.

Subject-Code Listing The Subject Index was formed by merging and editing the annual subject indexes. Because of year-to-year variations in subject headings, related papers do not always appear under the same heading in the merged index. To aid in cross-referencing the entries, each heading in the merged index is assigned a four-character code. For example, *Scanning tunneling microscopy* is *SC01*. All the subject codes associated with a paper are given with that paper each time it appears in any of the 400 subject listings. To aid in locating papers in the Subject Index, an alphabetical listing of the codes and subjects is provided.

Subject Index Entries in the Subject Index include the title of the paper, the last name of the first author, the volume and issue number (boldface), the beginning page number, the year of publication, and the codes of all other subjects pertaining to that paper.

Abstracts The Abstracts section lists papers chronologically by volume, issue, and year, in the order in which they appear in the table of contents of each issue. Individual entries show the title (boldface), authors, and beginning page number of each paper, followed by the abstract. For completeness, material which does not contain an abstract, such as a preface or a short communication, is noted by an entry which contains the title, author, and beginning page number.

Peter S. Hauge
Editor

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Analysis of Defect Distribution in Transistor Structures with Reflection and Transmission X-Ray Topography, *Howard,* **15-2,** 123 (1971). ***CR03 MA19 OP03 SE04 X-02***

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Paramagnetic Resonance of the Shallow Acceptors Zn and Cd in GaAs, *Title,* **7-1,** 68 (1963). ***CA01 DI08 GA01 LA04 RE08 ZI01***

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Abstracts 1957-1993

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Domain Orientation in Barium Titanate Single Crystals *by D. P. Cameron, p. 2.* An acid etching technique makes visible the domain structure of barium titanate crystals as reported by Hooton and Merz. Earlier observations by Merz of the mechanism of switching are confirmed by experiments using this technique. A discussion of domain wall formation in the orthorhombic state leads to the explanation of observed domain patterns. Photomicrographs are shown and discussed.

Design of Logic for Recognition of Printed Characters by Simulation *by E. C. Greanias, C. J. Hoppel, M. Kloomok, and J. S. Osborne, p. 8.* A logic for the recognition of printed characters employing a "proportional parts" method has been tested extensively by simulation. The proportional parts method relates the identity of a character to the relative size and position of character elements detected by optical scanning along closely spaced vertical lines. The video information from each scan is coded to designate the number, size, and position of inked areas detected by the scanner. The time sequence or order of occurrence of this coded information is tested by logical circuitry against prescribed sequences for character recognition. A set of coding definitions, a prescribed sequence for the recognition of a given character, and the methods of simulative testing of the recognition logic on the IBM Type 650 Magnetic Drum Data Processing Machine are discussed.

On the Theory of Relaxation Processes *by A. G. Redfield, p. 19.* A general procedure is given for finding the equation of motion of the density matrix of a system in contact with a thermal bath, as for example a nuclear spin system weakly coupled to a crystal lattice. The thermal bath is treated both classically and quantum mechanically, and the theory is similar to, and a generalization of, conventional theories of time proportional transition probabilities. Relaxation of the system by the thermal bath is expressed by a linear matrix operator, and it is stressed that elements of this operator can be regarded as secular or nonsecular perturbations on the equation of motion and can be treated accordingly. When the motion of the system is slow compared to that of the thermal bath, the equation of motion can be expressed in an operator form which is independent of representation. If the system has a time-dependent Hamiltonian which varies slowly compared to the motion of the thermal bath, the same equation of motion is obeyed and the system is relaxed by the bath toward a Boltzmann distribution with respect to its instantaneous Hamiltonian. If the time variation of the Hamiltonian is more rapid, higher order corrections to the equation of motion must be applied. The theory is applied to spin-lattice relaxation of a coupled nuclear spin system in a metal, for arbitrary externally applied fixed magnetic field.

A Three-Dimensional Printed Back Panel *by E. R. Wyma, p. 32.* A new design for interconnections of printed circuit packages in the IBM 608 Transistorized Computer is described. The three-dimensional arrangement for connections among circuit cards is shown to be flexible in design and adaptable to a highly mechanized manufacturing method. An arrangement for automatic cabling is discussed briefly. The various relationships among the design problems for circuit packaging, back panel connections and cabling are shown.

Clarification of First-Order Semiconduction Effects through Use of Electrochemical Potentials *by J. A. Swanson, p. 39.* When deviations from equilibrium conditions are small, the net rate at which electrons are interchanged between two groups of electrons which are separately in states of thermodynamic equilibrium is proportional to the difference of the Fermi levels applying to the two groups. With the help of this principle the first-order treatment of conduction effects in semiconductors (appropriate when carrier concentration

deviations are small) is considerably simplified. Poisson's equation is shown to be ignorable in the first-order treatment of steady-state effects. Application is given to the Hall effect and to the characterization of probes.

A Survey of Contact Resistance Theory for Nominally Clean Surfaces *by W. B. Ittner III and P. J. Magill, p. 44.* While the theory of electrical contact resistance is, for the most part, well known, it is difficult to apply directly to the prediction of experimental results since, in general, the theory involves microscopic parameters beyond the control of the investigator. Recent measurements of contact resistance as a function of the applied contact load, carried out under specified conditions, have yielded results which are in excellent agreement with the general theory. In contrast, however, to a number of previous publications, the results indicate that the contact area is determined completely by the applied load and an effective plastic yield pressure. Under conditions where contact wipe and vibration are held to a practical minimum, the contact area can be specified in terms of a plastic yielding mechanism down to pressures as low as 0.1 gram. In this region the bulk of the contact resistance is seen to be attributable, for nominally clean contacts, to an absorbed gaseous monolayer approximately two angstroms thick.

Development of the Electrostatic Clutch *by C. J. Fitch, p. 49.* A brief historical review of the electrostatic clutch operating on the Johnsen-Rahbek effect is presented. Mechanical design of a clutch, special lubrication, and the fabrication of electronically conductive clutch facing material are described. A high-speed, high torque-to-inertia ratio test model with bi-directional shaft control is described. With the clutch operating at 2500 rpm on 30 milliamperes at 150 volts, torques over 80 inch-pounds are available. The most useful single property of the electrostatic clutch is its fast response time. It can actuate levers, interposers, print hammers, optical gates, etc., in fractions of a millisecond; it can accelerate shafts to high rpm's with moderate loads in a few milliseconds from extremely low input control energy.

An Analysis of Diffusion in Semiconductors *by S. Zaromb, p. 57.* In the experimental determinations of the coefficients of diffusion of impurities in semiconductors reported to date, it has usually been assumed that these coefficients do not vary with concentration. This assumption is questioned here. Interactions between acceptors, donors, electrons, and holes may lead to complicated diffusion equations, as shown by an analysis based on Onsager's theory. In particular, appreciable covalent compound formation is likely to occur between some substitutional donors and acceptors. This alone may lead to a marked dependence of diffusion coefficients on concentration, and to diffusion of acceptors induced by concentration gradients of donors and vice versa. Such effects are suggested by some discrepancies in the experimental results reported thus far.

The Random-Access Memory Accounting Machine—I. System Organization of the IBM 305 *by M. L. Lesser and J. W. Haanstra, p. 62.* The design features of a new automatic data processing machine for business applications, utilizing a random-access memory system, are described. Unlike the usual "batch" method of machine-processing business transactions, the technique used permits transfer of information between any two points in the system and allows multi-choice decisions according to the current status of the information. The "in-line" operational concept is discussed in detail and the data transfer routes and processing controls are shown. Employing punched-card input and printed-record output, the IBM 305 accounting machine is designed to handle 10,000 line-transactions per day.

The Random-Access Memory Accounting Machine—II. The Magnetic-Disk, Random-Access Memory *by T. Noyes and W. E. Dickinson, p. 72.* The design features are described of a new large-capacity memory device having random access to information stored magnetically on rotating disks. The mechanical arrangement of an array of 50 disks is shown, and details are given of the pair of magnetic recording heads, which are spaced accurately from the disk surface by air jets. The access mechanism and the timing system for positioning the heads on the disk tracks are described. The total storage capacity of the system is 5,000,000 alphanumeric characters.

Logical Design of the Digital Computer for the SAGE System *by M. M. Astrahan, B. Housman, J. F. Jacobs, R. P. Mayer, and W. H. Thomas, p. 76.* Special design features and performance criteria are described for the logical system in the digital computer used in the SAGE (Semi-Automatic Ground Environment) air defense system. Design details are given for the arithmetic element, high-speed multiply, index registers, input-output control, and magnetic drum buffer. The system is designed according to special military application requirements of speed, capacity, reliability and flexibility.

Simple Constant-Temperature Oven and Control System *by G. R. Gunther-Mohr and S. Triebwasser, p. 84.* A number of laboratory measurements require a constant and uniform ambient temperature. A thermocouple-monitored system consisting of an oven, a stable reference source and a chopper-amplifier controller unit has been developed. This system provides a stable and uniform temperature, ±0.1°C from 200° to 1050°C in a cylindrical region 5 cm in diameter and 12 cm long. Each of the parts of the system is discussed and their operation as an integrated whole considered.

Lattice Parameters of Zn_3As_2 *by H. Cole, F. Chambers, and H. Dunn, p. 90.*

A General Theory of Multiple Spin Echoes *by J. W. Horton, p. 93.*

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A 32,000-Word Magnetic-Core Memory *by E. D. Foss and R. S. Partridge, p. 102.* The development of the IBM 738 magnetic core storage unit is described and associated engineering problems are discussed, including the electrical and mechanical arrangements for packaging more than one million magnetic cores and their circuits. This paper describes the driver circuits and the sense amplifier used for this system.

Computation of e^N for $-\infty < N < +\infty$ Using an Electronic Computer *by E. G. Kogbetliantz, p. 110.* Rational R and polynomial P approximations to the exponential function e^N are studied. They allow e^N to be computed for any value of the exponent N in the infinite range from minus infinity to plus infinity a minimum number M of multiplications (and divisions, for the rational approximations). This minimum is attained without unduly increasing the number PC of precomputed and stored constants and also without limiting the number Dg of the first correct significant digits.

The Multipurpose Bias Device—Part I: The Commutator Transistor *by B. Dunham, p. 116.* It is suggested that multipurpose devices will provide economy in both number and assortment of basic computer building blocks. A study is made of the Rutz commutator transistor largely in application to three-input, one-output logical situations. A basis is thereby provided for a more general analysis to be published at a later date.

Addressing for Random-Access Storage *by W. W. Peterson, p. 130.* Estimates are made of the amount of searching required for the exact location of a record in several types of storage systems, including the index-table method of addressing and the sorted-file method. Detailed data and formulas for access time are given for an "open" system which offers high flexibility and speed of access. Experimental results are given for actual record files.

The Lorenz Number *by P. J. Price, p. 147.* The theory of the Lorenz number of a conducting crystal is developed for the common models of the electron assembly. For the one-electron model it is shown that, provided scattering is elastic to an approximation which is examined, the Lorenz number is equal to the square fluctuation of the thermoelectric power. For the phenomenological band model an equivalent result is obtained. It is hypothesized that these results are special cases of a more general one. Some applications, including the theory of the bipolar anomaly for semiconductors, are discussed.

A Positive-Integer Arithmetic for Data Processing *by R. W. Murphy, p. 158.* It is hypothesized that positive numbers suffice for the expression of quantities in accounting. New arithmetic operations are devised that yield non-negative results in computation, and the applicability of these operations to data processing is studied. These operations permit a wide variety of functions to be computed with fewer and less complex steps and imply the feasibility of constructing less complex data-processing machines.

Irredundant Disjunctive and Conjunctive Forms of a Boolean Function *by M. J. Ghazala, p. 171.* A thorough algebraic method is described for the determination of the complete set of irredundant normal and conjunctive forms of a Boolean function. The method is mechanical and therefore highly programmable on a computer.

A Mathematical Model for Determining the Probabilities of Undetected Errors in Magnetic Tape Systems *by M. Schatzoff and W. B. Harding, p. 177.* Mathematical models for evaluating the relative efficiencies of vertical and longitudinal redundancy-bit checking in magnetic tape systems are derived. Although these types of validity checking have been in use for some time, this is, to the authors' knowledge, the first quantitative statement of the probabilities associated with them.

A Self-Clocking System for Information Transfer *by L. D. Seader, p. 181.* This paper describes a circuit which generates a continuous train of clock pulses bearing a fixed phase relationship to information pulses. By switching two gated oscillators, the information pulses continuously correct the phase of the clock pulses.

A Symmetrical-Transistor Steering Circuit *by J. L. Walsh, p. 185.*

Determination of Transient Response of a Drift Transistor Using the Diffusion Equation *by H. B. von Horn and W. Y. Stevens, p. 189.*

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Development of the Permissive-Make Relay *by B. J. Greenblott and J. E. Wallace, p. 198.* The development of a new relay is described which meets the need for an improved general-purpose relay for use in existing and future business machines. Long life, reliability, higher speed, low power input and manufacturing economy are realized in the Permissive-Make Relay through the following factors: a new contact system; a balanced force system; optimum magnet design; limited tolerance buildup; adjustment-free assembly design.

Two-Collector Transistor for Binary Full Addition *by R. F. Rutz, p. 212.* Details are given of the design and operational features of two versions of a new multielectrode transistor which serves as a full adder for binary numbers in computer circuits. This transistor in a simple circuit connection performs the logical operations "and," "or," "exclusive or," "if-and-only-if," "neither-nor," "not both," and "not." The point-contact design utilizes two collectors with high current multiplication factors to provide signal amplification during

the logical operation at very high speeds. The "all-junction" design utilizes *p-n* hook collectors to give much higher values of intrinsic alpha. The paper describes the nature of the internal positive-feedback action in the two-collector transistors and illustrates the function of these transistors as logic devices.

Spatial Variation of Currents and Fields Due to Localized Scatterers in Metallic Conduction *by R. Landauer, p. 223.* Localized scatterers can be expected to give rise to spatial variations in the electric field and in the current distribution. The transport equation allowing for spatial variations is solved by first considering the homogeneous transport equation which omits electric fields. The homogeneous solution gives the purely diffusive motion of current carriers and involves large space charges. The electric field is then found, and approximate space charge neutrality is restored, by adding a particular solution of the transport equation in which the electric field is associated only with space charge but not with a current. The presence of point scatterers leads to a dipole field about each scatterer. The spatial average of a number of these dipole fields is the same as that obtained by the usual approach which does not explicitly consider the spatial variation. Infinite plane obstacles with a reflection coefficient r are also considered. These produce a resistance proportional to $r/(1-r)$.

Microwave Amplification by MASER Techniques *by W. V. Smith, p. 232.* A new amplification principle, that of Microwave Amplification by Stimulated Emission of Radiation (MASER), has already demonstrated its potentialities for low-noise, narrow-band amplification. The present note presents an elementary analysis of MASER operation, including its potentiality for broadband, short-transit-time amplification.

The Linear Hall Effect *by P. J. Price, p. 239.* A new method for handling the Boltzmann equation is used to obtain, without approximation, a general formula for the linear Hall effect in a solid electronic conductor. Expressions for the conductivity in no magnetic field and for the quadratic magnetoconductivity are also obtained. These formulas introduce a vector mean free path, not in general parallel to the electron velocity, which is related to the velocity by an integral equation. Some possible cases of the formula for the Hall effect are analyzed. The solution of the integral equation for the vector mean free path is discussed, and methods of approximation are proposed.

Literary Data Processing *by P. Tasman, p. 249.* A method is presented for rapid compilation of analytical indexes and concordances of printed works, using either a conventional punched-card system or an electronic data processing machine. A detailed description of the procedures used in automatically analyzing and indexing the *Summa Theologica* of St. Thomas Aquinas is given. Reference is also made to the indexing of the Dead Sea Scrolls using an IBM 705.

An Experimental 50-Megacycle Arithmetic Unit *by R. M. Walker, D. E. Rosenheim, P. A. Lewis, and A. G. Anderson, p. 257.* An experimental 50-megacycle arithmetic unit has been built which performs a repetitive multiplication program and checks the results for errors. The unit uses pulse circuitry which has been developed to perform digital operations at a 50-megacycle pulse-repetition rate. This paper describes the arithmetic system and the circuits which perform the required functions. These circuits include a full binary adder, a phase-locked frequency divider which provides a 3.125-megacycle secondary timing source, a reshaping and retiming circuit using germanium diodes and capacitive storage, a high-speed shift register, a high-speed indicator register, and a binary word generator.

Various novel features of a digital system operating at these high speeds are described. These include the use of coaxial delay lines for the distribution of signals and as storage elements, and the use of secondary emission tubes in amplifier and multivibrator circuits.

In a 50-megacycle system the interdependence of the space and time dimensions is marked, and although this introduces problems which are not ordinarily encountered in computing systems, it may be used advantageously to provide features such as the variable-phase clock system used in the arithmetic unit.

The performance and reliability of the arithmetic unit are discussed as well as the reliability of the components and circuits which make up the system. Although the techniques and circuitry discussed here have been applied only to a relatively simple arithmetic unit, it is felt that they could be useful in a variety of high-speed computing and measurements applications.

Microsectioning: A Metallographic Technique for Semiconductor Devices *by J. S. Hanson, p. 279.* A microsectioning technique is described that enables metallographic sectioning of fragile semiconductor devices without the difficulties and specimen damage associated with the use of conventional techniques. Major advantages are (a) maintenance of a planar surface on specimens having adjoining areas of widely varying physical characteristics, (b) preservation of boundary details between such areas by elimination of rounding-off effects, and (c) precise positioning of the sectioning plane by direct micrometer caliper measurement. Choice of sectioning plane, specimen mounting, machine lapping of mounted specimens, polishing, etching, and panoramic microphotographic techniques are described. The effectiveness with which data can be gathered from the resulting microphotographs is demonstrated by an analysis and evaluation of selected specimen photographs.

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Preface *by D. R. Young, p. 294.*

Trapped-Flux Superconducting Memory *by J. W. Crowe, p. 294.* A memory cell based on trapped flux in superconductors has been built and tested. The cell is constructed entirely by vacuum evaporation of thin films and can be selected by coincident current or by other techniques, with drive-current requirements less than 150 ma. The short transition time of the trapped-flux cell indicates its possible use in high-speed memories. The superconductive film memory does not exhibit the problems of "delta noise" in core memories resulting from the difference in half-select pulse outputs.

An Analysis of the Operation of a Persistent-Supercurrent Memory Cell *by R. L. Garwin, p. 304.* From a thin-film persistent-supercurrent memory cell is abstracted a particular theoretical model which is discussed exactly and in detail. The behavior predicted is in good agreement with that of experimental devices built to be as closely like the model as was possible at the time. Partly because of the simplicity of the analysis and the rather complete understanding thus gained, this model may prove to be useful for the design of large-scale memory and computing systems. For a single cell, a memory cycle time of 5 millimicroseconds should be achievable, and for a large memory perhaps 10 millimicroseconds.

A Statistical Approach to Mechanized Encoding and Searching of Literary Information *by H. P. Luhn, p. 309.* Written communication of ideas is carried out on the basis of statistical probability in that a writer chooses that level of subject specificity and that combination of words which he feels will convey the most meaning. Since this process varies among individuals and since similar ideas are therefore relayed at different levels of specificity and by means of different words, the problem of literature searching by machines still presents major difficulties. A statistical approach to this problem will be outlined and the various steps of a system based on this approach will be described. Steps include the statistical analysis of a collection of documents in a field of interest, the establishment of a set of "notions" and the vocabulary by which they are expressed, the compilation of a thesaurus-type dictionary and index, the automatic encoding of documents by machine with the aid of such a dictionary, the encoding of topological notations (such as branched structures), the recording of the coded information, the establishment of a searching pattern for finding pertinent information, and the programming of appropriate machines to carry out a search.

The Effect of an Electric Field on the Transitions of Barium Titanate *by M. E. Drougard and E. J. Huibregtse, p. 318.* A review is presented of the effects of electric fields on the ferroelectric phase transitions of barium titanate at 120°C and 5°C. The double hysteresis loop observed at the Curie point and the triple hysteresis loop and dielectric constant measured at the 5°C transition are examined in the light of Devonshire's thermodynamic theory of ferroelectricity in barium titanate. The data and various published experimental results are shown to agree with calculations based on the Devonshire free-energy function. The discrepancy between the coercive fields predicted by the theory and those actually observed is discussed.

A Mechanical Heart-Lung Apparatus *by R. Taylor, p. 330.* An apparatus is described for taking over the functions of the human heart and lungs for short periods of time to permit a surgeon to perform certain open-heart surgical procedures in a blood-free field. This equipment is capable of receiving venous blood from the patient, removing excess carbon dioxide and restoring the proper oxygen content, and finally of pumping the blood back into the patient's arterial system. The heart-lung apparatus is provided with controls that automatically maintain the pH of the blood at its correct value, maintain proper blood temperature and safeguard the patient against unwanted changes in blood volume and against excessive blood pressure during the course of the operation. The machine requires the attention of only two persons during normal surgical procedures.

The Formalization of Scientific Languages—Part I: The Work of Woodger and Hull *by B. Dunham, p. 341.* The extent to which scientific languages can be formalized is an important problem, especially if it is assumed that a theorem-proving machine will deal most effectively with formal systems. In Part I, the axiomatic attempts of Woodger in genetics and of Hull in the theory of rote learning are examined. In Parts II and III, to be published later, the more prominent efforts to formalize physical theory will be considered and a general study will be made of related questions.

A Radiant-Energy Heater Using an Ellipsoidal Reflector *by E. H. Nicollian, G. R. Gunther-Mohr, and L. R. Weisberg, p. 349.* The effectiveness of a radiant-energy heater employing a hemi-ellipsoidal aluminum reflector and an incandescent lamp as radiation source is illustrated by application to the zone-melting of germanium. The factors affecting the design and performance of this heater are discussed.

A Binary-Weighted Current Decoder *by E. J. Smura, p. 356.* A novel method for driving cathode-ray-tube deflection yokes from digital equipment has been found. The system is compared with other methods and outstanding features are described. The important design parameters are outlined and their effect on circuit operation noted. A printed-circuit-package assembly of a typical converter using this system is shown.

Radio-Interference Control as Applied to Business Machines *by J. M. Sarley and R. J. Hendery, p. 363.* This paper discusses certain known characteristics and sources of radio interference and methods used to reduce the interference levels present in business machines. Particular attention is given to electro-mechanical machines ranging from a simple card perforator, operated by an electrical contact and an electromagnet, to electronic data-processing machines. The sources of interference in these machines are found in a wide variety of components and circuit configurations, such as electrical contacts, gas tubes, unterminated transmission lines and motors.

Some of the problems encountered in reducing this interference to a satisfactory level are described. Testing methods are also considered. A description is given of the development of a universal line filter which has been most successful in reducing noise transmission over power cables.

The development of reinforced plastic machine covers presents a special problem in radio-interference control. A discussion is given of experimental solutions to this problem through the use of such techniques as copper screening, copper spray, and imbedded metallic foils.

Superconducting Connections to Films *by J. A. Kurtz, p. 373.*

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A Learning Machine: Part I *by R. M. Friedberg, p. 2.* Machines would be more useful if they could learn to perform tasks for which they were not given precise methods. Difficulties that attend giving a machine this ability are discussed. It is proposed that the program of a stored-program computer be gradually improved by a learning procedure which tries many programs and chooses, from the instructions that may occupy a given location, the one most often associated with a successful result. An experimental test of this principle is described in detail. Preliminary results, which show limited success, are reported and interpreted. Further results and conclusions will appear in the second part of the paper.

An Error-Sampled Sweep-Position Control System *by C. H. Knapp, E. Shapiro, and R. A. Thorpe, p. 14.* This paper illustrates the application of sampled-data theory to the synthesis of a feedback control system using forward-path digital compensation to achieve high accuracy and fast response. It also presents a detailed description of the design and operation of a transistor system prototype. Developed for the specific purpose of controlling the position of an instantaneous portion of a cathode-ray-tube trace, the system has a number of unusual characteristics such as transport lag, digital integration, and numerous sampling rates. The practical manner in which these characteristics are implemented and the mathematical techniques used for system analysis should prove applicable to a wide variety of control-system problems.

Magnetic-Recording-Head Selection Switch *by L. D. Seader, p. 36.* A switch for selecting one out of 100 magnetic recording heads for reading or writing is described. The recording heads are arranged in a 10 by 10 matrix and the switching is accomplished by semiconductor devices. The problem of obtaining suitably fast current rise time during writing is discussed, and the problem of crosstalk from unselected recording heads during reading is analyzed. Experimental results illustrate the performance of the switch.

Computation of Arctan N for $-\infty < N < +\infty$ Using an Electronic Computer *by E. G. Kogbetliantz, p. 43.* Rational (R) and polynomial (P) approximations to Arctan N are studied with the aim of computing this function, to any prescribed accuracy and without unduly increasing the number PC of stored constants, in a minimum number M of multiplications (and divisions for R approximations). The number Dg of first correct *significant* digits in principle is not bounded. The results corresponding to the values 8, 10, 18 and 20 of this number are as follows: (Table of results is given for M ranging in value from 4 to 10.)

If M is increased, subroutines with smaller PC are easily deduced from our general results. Thus, for instance, rational approximations with $Dg = 6$ can be obtained in three multiplications only, if $PC = 19$ (combination $m^* = 3$, $q = 10$); but the same accuracy $Dg = 6$ characterizes also the cases $M = 4$ with $PC = 11$ and $M = 5$ with $PC = 7$ (combinations $m^* = 4$, $q = 6$ and $m = 5$, $q = 4$).

If polynomial approximations are used, $Dg = 6$ is obtained for $M = 5$, $PC = 7$, but also for $M = 4$ and $PC = 11$. No subroutines with a stored table of values of Arctan x are considered.

Effects of Low Temperatures on Transistor Characteristics *by A. B. Credle, p. 54.* The four-pole parameters of a group of similar *pnp* alloy junction transistors were measured in the frequency range from 0.5 to 5 mc and from room temperature down to that of liquid nitrogen. The measured parameters are translated into simple electrical networks for application in these frequency and temperature ranges.

Theoretical expressions for the transistor parameters are evaluated. This evaluation utilizes the effects of temperature on surface-recombination effects, on hole mobility, and on carrier lifetime that have been reported in the literature.

The transistors were subjected to grounded-emitter pulse tests in which the transistors were driven from beyond cutoff to the edge of saturation. These tests show that, for a given output pulse current, rise time decreases with temperature. The tests with the transistor in liquid nitrogen show further that rise time decreases as the output current pulse increases. Under these conditions it is possible for a 30 mw, 3 mc alloy-junction transistor to deliver a one-ampere output current pulse with a rise time of a few tenths of a microsecond and with a grounded-emitter gain of about 20.

A New Approach to Small-Computer Programming and Control *by J. J. Lentz, p. 72.* A novel approach to computer programming and control, used in the IBM 610 computer, allows the solution of complex problems by an operator whose only previous experience with computing has been the desk calculator. The machine's command structure is designed so that the operator can at all times communicate with the computer by a series of short sentence-type instructions closely resembling the steps of manual arithmetic solution. A type of floating-decimal operation called the "auto-point" mode permits entry of data into storage locations with automatic positioning of the decimal point, without elaborate programming. The decimal point is automatically re-positioned during subsequent computation.

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High-Resolution Magnetic Recording Structures *by A. S. Hoagland, p. 90.* Design concepts are established for several high-resolution magnetic recording structures, and their application demonstrated. The conventional ring head is treated and two new devices are described. A probe-type unit

is discussed which shows promise in high-density vertical magnetic recording. A wire-grid array is also advanced to outline a unique conceptual approach to the achievement of higher resolution.

Programs as a Tool for Research in Systems Organization *by J. Jeenel, p. 105.* A program for the solution of a problem by a data-processing system constitutes a conceptual link between the problem and the machine. It is proposed that both problems and machine organization be studied in terms of programs. A data-processing system may for this purpose be considered a collection of units such as arithmetic units and stores of different types and characteristics. A standard representation of programs is proposed for studying the organization of systems composed of processing units and stores. This approach may lead to more efficient and systematic design of data-processing systems as well as to improved programming methods for existing machines.

On the Statistical Mechanics of Impurity Conduction in Semiconductors *by P. J. Price, p. 123.* The statistical mechanics of the impurity electron states for a semiconductor with a low density of donors, and a small amount of acceptor compensation, is analyzed. Expressions are obtained for the number of dissociated donor ion states according to the Mott model, and for the effects of multiple trapping, and of dispersion of the trapping energies, on this number. An expression for the thermoelectric power according to the Mott model is obtained. If a small proportion of "minority" donors, of a different chemical species with a smaller electron binding energy than the majority donors, were added to the impurity content they should act as additional traps for donor ion states: The statistical mechanics of this system is analyzed.

Pulse Time Displacement in High-Density Magnetic Tape *by R. A. Skov, p. 130.* In computer magnetic tape systems, a primary factor in character rate is recording density. Pulse time displacement places a direct limit on the maximum bit density which may be used in parallel NRZI recording systems in which recovery of the information on readback depends on correct synchronism of all tracks. Measurement techniques for evaluation and analysis of pulse time displacement are described. A sawtooth oscilloscope display is particularly useful for observing time displacement as a function of time. The various components of time displacement and their causes, such as skew and pulse crowding, and methods used to reduce them are discussed. This study led to the adoption of a recording density exceeding 500 bits per inch for the IBM 729-III Magnetic Tape Unit.

Reliability Improvement by the Use of Multiple-Element Switching Circuits *by W. E. Dickinson and R. M. Walker, p. 142.* Physical devices used for switching have finite probabilities of failure. Circuits which make use of redundancy to achieve resultant reliabilities greater than that of their elements have been proposed and have been analyzed for the case of intermittent failures. The present paper extends certain of these results to the case of permanent failures of the elements, assuming that the reliability of these elements is known. It is shown that, for operating periods which are short compared to the mean time to failure of the elements, a substantial increase in reliability can be obtained by such redundancy.

Reliability Improvement through Redundancy at Various System Levels *by B. J. Flehinger, p. 148.* Improvement in computing machine reliability through redundancy is studied as a function of the level at which the redundancy is applied. The reliability achieved by redundancy of complete, independent machines is compared to that achieved by redundancy of smaller units.

A machine unit is termed m times redundant when the following conditions exist:

1. m independent identical units operate simultaneously with a common input.

2. A failure detector is associated with each unit.

3. A switch is connected to the outputs of the units, so that the output is taken from some one unit until failure occurs in that unit. Then the switch steps so that the output is taken from the next redundant unit, if that unit is operating correctly. The process continues until the assigned task is completed or all m units fail.

The reliability of m redundant units is expressed in terms of the reliability of one unit and the probabilities of correct operation of the failure detectors and switch.

It is assumed that a complete machine may be broken up into p units, $p = 1, 2, 3, \ldots, 24$, of equal reliability. The reliability achieved by redundancy of these units is calculated as a function of p and m, $m = 1, 2, 3, 4$, with single-machine reliabilities of 0.2, 0.5, 0.9 and 0.99. These results are calculated for perfect failure detection and switching devices as well as for moderately unreliable devices. The resultant system unreliability is plotted as a function of p on linear and on logarithmic scales.

The Automatic Creation of Literature Abstracts *by H. P. Luhn, p. 159.* Excerpts of technical papers and magazine articles that serve the purposes of conventional abstracts have been created entirely by automatic means. In the exploratory research described, the complete text of an article in machine-readable form is scanned by an IBM 704 data-processing machine and analyzed in accordance with a standard program. Statistical information derived from word frequency and distribution is used by the machine to compute a relative measure of significance, first for individual words and then for sentences. Sentences scoring highest in

significance are extracted and printed out to become the "auto-abstract."

On Checking an Adder *by W. W. Peterson, p. 166.* It is widely known that a computer adder can be checked by a completely independent circuit using check symbols that are residues of the numbers modulo some base. This paper describes such a residue checking system and shows, moreover, that independent adding and checking circuits are possible only with systems of this type. The discussion includes a method of handling residue-class check symbols when overflow occurs.

A Note on the Computation of Eigenvalues and Vectors of Hermitean Matrices *by T. C. Chen and R. A. Willoughby, p. 169.*

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A Direct-Reading Printed-Circuit Commutator for Analog-to-Digital Data Conversion *by C. A. Walton, p. 178.* A novel direct-readout printed-circuit commutator has been incorporated in the design of a shaft-to-digital converter system for analog-to-digital data conversion. The design avoids the use of supplementary coding or additional translation circuitry required to operate other shaft-to-digital converters. Methods are described for ensuring logical progressions of numerical data despite gearing errors and the analog nature of the input-shaft position. Some applications of the commutator are discussed.

Phase Equilibria in the Ferrite Region of the System Manganese-Iron-Oxygen *by M. W. Shafer, p. 193.* An important factor in growing crystals from the melt is an understanding of the phase relationships for systems involving the necessary elements. This investigation deals with the determination and interpretation of these relationships in the ferrite region of the system Mn-Fe-O and points out the conditions necessary to grow crystals along with the Mn_3O_4-Fe_3O_4 join.

The results are presented in terms of a phase diagram which shows isotherms, isobars, and fractionation curves, the data necessary to predict the exact crystallization path of compositions which fall in the ferrite region.

Several crystallization paths are discussed and their relationship to crystal growth pointed out. Liquids falling on the Mn-Fe side of the Mn_3O_4-Fe_3O_4 join are deficient in oxygen and on cooling will precipitate a lower oxide phase in addition to a stoichiometric ferrite. On the other hand, ferrite crystals separating from liquids whose compositions fall on the oxygen side of the join can have excess oxygen (cation vacancies).

The Physical Interpretation of Mean Free Path and the Integral Method *by P. J. Price, p. 200.* In previous papers, general expressions for the linear electronic transport constants of solids were obtained in terms of a conjugate function $\psi^\dagger$ related, by a linear inhomogeneous integral equation, to the function (of electron state) ψ measured by the "flux." It is now shown that

$$\tau\psi^\dagger = \int_0^\infty \psi(t)\, dt\,,$$

where the integrand is the expectation of ψ for an electron which at time t earlier was in the specified state (of which $\psi^\dagger$ is a function) and $1/\tau$ is the collision frequency. In particular, the vector mean free path $\tau v^\dagger$ is: "the limit, after a virtually infinite time, of the mean displacement, in Brownian motion, of the position of an electron initially in the specified state." If there is a force (e.g. that due to a magnetic field) accelerating the electrons between collisions, then a linear transport constant is the same functional of an "extended conjugate" $\psi^{\dagger e}$ as it is of $\psi^\dagger$ in the absence of the force. It is shown that $\tau\psi^{\dagger e}$ is obtained (instead of $\tau\psi^\dagger$) when the integrand in the integral above is replaced by the "expectation after time t" as modified by the accelerations between collisions. The relation of the present formalism to the Shockley-Chambers theory is discussed.

A Load-Sharing Matrix Switch *by G. Constantine, Jr., p. 204.* A matrix-switch winding pattern has been developed which allows the power from several pulse generators to be combined into a single high-power pulse to drive a computer core memory. This pulse may be directed into one of a group of outputs. The method of operation, including the logical basis for changes in number of outputs, is described.

The device is suitable for the *X-Y* drivers of a transistor-driven core memory because one switch allows a group of fast, low-power transistors to deliver a large drive pulse to one drive line on one side of the memory. A 16-output load-sharing matrix switch has been used in the *X-Y* drive system for a 2-μsec memory.

Study of the Second-Order Ferroelectric Transition in Tri-Glycine Sulfate *by S. Triebwasser, p. 212.* Results of measurements of the dielectric constant, dielectric nonlinearity and spontaneous polarization of tri-glycine sulfate are given. These data demonstrate clearly that this material exhibits a second-order ferroelectric transition. The properties discussed are described in terms of the usual expansion of the free energy in even powers of the polarization

$$F(P,T) = F(O,T) + A(T - T_0)P^2 + BP^4 + CP^6,$$

where A, T_0, B and C are constants and T and P are the temperature and polarization, respectively. From the various data taken it is found that $A = 1.96 \times 10^{-3}\ (°C)^{-1}$, $T_0 = 49.8°C$, $B = 2.0 \times 10^{-10}\ (\text{esu/cm}^2)^{-2}$ and $C = 8.4 \times 10^{-19}\ (\text{esu/cm}^2)^{-4}$. From these results the nonlinearity of the dielectric constant above the Curie point is calculated at various temperatures.

Computation of Arcsin N for $0 < N < 1$ Using an Electronic Computer *by E. G. Kogbetliantz, p. 218.* All known subroutines for Arcsine are based on the relation Arcsin N = Arctan $[N/(1 - N^2)^{1/2}]$. Therefore, Arcsine is not computed as such but as an Arctangent.

To avoid the loss of machine time caused by the computation of $N/(1 - N^2)^{1/2}$, a direct computation of Arcsine is proposed. A subroutine yielding the first six correct significant digits in only five multiplications and divisions is described in detail to illustrate the new method's rapidity. The same number of five operations is necessary to compute, knowing N, the number $N/(1 - N^2)^{1/2}$.

A Full Binary Adder Employing Two Negative-Resistance Diodes *by J. W. Horton and A. G. Anderson, p. 223.* Full binary pulse addition may be performed using only two negative-resistance diodes. Amplified Sum and Carry outputs can be provided which are virtually in coincidence with the input signals. A full adder is described, employing Reeves-Cooke positive-gap diodes which operate with pulses of 20-millimicrosecond duration.

Curve Fitting for a Model of Applied Research and Development Scheduling *by P. V. Norden, p. 232.* Analysis of the research and development process has suggested improved techniques for estimating the anticipated effort requirements for engineering projects. Logistic growth curves have been fitted to the time distribution of cumulative man-hours, and an effort-distribution array permits the extraction of meaningful information from historical cost records. These provide a consistent basis for adjusting current project schedules and making further estimates.

The Bipolar Righi-Leduc Effect *by P. J. Price, p. 249.*

Magnetic Field Plotter for Superconducting Films *by H. E. Kronick, p. 252.*

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Communication Sciences in a University Environment *by J. B. Wiesner, p. 268.* Information processes and information processing systems are the principal concerns of investigators in many fields, including electrical engineering, neurophysiology, psychology, linguistics, genetics and mathematics. Studies in each of these fields contribute to understanding in the others, and each has a need for mathematical models and mathematical methods for describing and analyzing these processes. Studies of electrical communication and computational systems have provided the mathematical tools and understanding which are useful to the other fields. The related interests of this diverse group of scientists are examined and the activities of several groups in the Communication Sciences Center at M.I.T. are described.

Problems in Scientific Communication *by E. de Grolier, p. 276.*

How Much Science Can You Have at Your Fingertips? *by I. J. Good, p. 282.* Numerous suggestions are presented for helping men to learn and retrieve scientific information, with or without artificial aids.

In a discussion of how much information can be stored in a human brain, and how this compares with the amount of scientific information that has been published, it is argued that the number of "conceivable" states of the brain is much larger than the number of attainable states. It is necessary here to use a definition for the number of effective states of a brain or of any record.

It is mentioned that access to published literature is not the only problem in the communication of scientific information.

A discussion of how a man might acquire an encyclopedic knowledge emphasizes, for example, that a vital principle in learning and teaching is an explicit belief in the importance of general principles.

Knowledge is compared with a network having various impedances in the connections between the nodes, somewhat like a nervous system. Difficulties in classification (and in organization) appear when networks depart very much from having a tree-like structure. Some tentative suggestions for learning arise out of this model.

Possible new fields of research, such as *saporology*, and of new periodicals, such as *Half-Baked Ideas*, are touched upon.

A discussion of the value of mechanical aids concludes with a list of probable new advances in consulting scientific literature in the near future. Sixteen applications are listed for tape recordings of books.

The paper concludes with a warning that some of the world's greatest scientists have done their best work when they were given plenty of time to think their own thoughts.

Channels with Side Information at the Transmitter *by C. E. Shannon, p. 289.* In certain communication systems where information is to be transmitted from one point to another, additional side information is available at the transmitting point. This side information relates to the state of the transmission channel and can be used to aid in the coding and transmission of information. In this paper a type of channel with side information is studied and its capacity determined.

Artificial Auditory Recognition in Telephony *by E. E. David, Jr., p. 294.* Machines which automatically recognize patterns from a stream of acoustic events, for example a spoken command, would have great utility in both communications and data processing. This paper reviews two

applications of an elementary recognizer to the problem of actuating certain logical functions, and indicates how more ambitious recognizers might be utilized. In this regard, the automatic measurement of a talker's voice pitch and voicing dynamics appears fundamental to speech analysis, and hence to many recognition schemes. Visual inspection of spectral data taken from different speakers supports this contention.

Segmentation of speech into discrete units suitable for recognition, including the possibility of overlapping elements, is discussed. There is reason to expect that such segments will span several elementary speech sounds (phonemes). To illustrate this approach, a set of rules is presented for associating visual spectral displays (sound spectrograms) with the perception evoked by the corresponding utterances. These rules are specifically tailored for a limited vocabulary consisting of ten spoken numbers, and were validated by naive subjects who used them to identify the utterances of 33 people. In a further experiment, spectrograms of the same material from 14 talkers were simplified by reducing them to binary elements. It was found that master patterns for each number, compiled from the ensemble of talkers, could identify the utterances with over 99% success. These results emphasize a "diversity" approach to speech recognition which operates on relations between gross spectral features and does not depend exclusively on any one property.

The Role of Large Memories in Scientific Communications *by M. M. Astrahan, p. 310.* Large memories provide automatic reference to millions of words of machine-readable coded information or to millions of images of document pages. Higher densities of storage will make possible low-cost memories of billions of words with access to any part in a few seconds or complete searches in minutes. These memories will serve as indexes to the deluge of technical literature when the problems of input and of the automatic generation of classification information are solved. Document files will make the indexed literature rapidly available to the searcher. However, memory capacity is currently well ahead of our ability to use it, and much work remains in this area. Machine translation of languages and recognition of spoken information are two other areas which will require fast, large memories.

A Business Intelligence System *by H. P. Luhn, p. 314.* An automatic system is being developed to disseminate information to the various sections of any industrial, scientific or government organization. This intelligence system will utilize data-processing machines for auto-abstracting and auto-encoding of documents and for creating interest profiles for each of the "action points" in an organization. Both incoming and internally generated documents are automatically abstracted, characterized by a word pattern, and sent automatically to appropriate action points. This paper shows the flexibility of such a system in identifying known information, in finding who needs to know it and in disseminating it efficiently either in abstract form or as a complete document.

Chess-Playing Programs and the Problem of Complexity *by A. Newell, J. C. Shaw, and H. A. Simon, p. 320.* This paper traces the development of digital computer programs that play chess. The work of Shannon, Turing, the Los Alamos group, Bernstein, and the authors is treated in turn. The efforts to program chess provide an indication of current progress in understanding and constructing complex and intelligent mechanisms.

Intelligent Behavior in Problem-Solving Machines *by H. L. Gelernter and N. Rochester, p. 336.* As one step in the study of intelligent behavior in machines, the authors consider the particular case of a machine that can prove theorems in elementary Euclidean plane geometry. The device uses no advanced decision algorithm, but relies rather on rudimentary mathematics and "ingenuity" in the manner, for example, of a clever high-school student.

This paper discusses heuristic methods and learning machines and introduces the concept of a theory machine as an extension of a theorem-proving machine.

Computation in the Presence of Noise *by P. Elias, p. 346.* The behavior of a system consisting of a preliminary coder, an unreliable computer, and a decoder is investigated. Coding input blocks of k binary digits into output blocks of $n>2k$ binary digits, it is shown that a simple combinational computer which can take the *and* or *or* of k or more input blocks can only be made arbitrarily reliable by making n/k arbitrarily large, so that the capacity for computation, in an information theory coding sense, is zero. Incomplete results for a single *and* or *or* circuit give the same result if the output gives no information about the inputs except for the information about their *and* or *or*; if this is not demanded, then for $n>2k$, reliable computation through noisy computing circuits is possible, but the computing is done in the decoder.

Machine-Made Index for Technical Literature—An Experiment *by P. B. Baxendale, p. 354.* Machine techniques for reducing technical documents to their essential discriminating indices are investigated. Human scanning patterns in selecting "topic sentences" and phrases composed of nouns and modifiers were simulated by computer program. The amount of condensation resulting from each method and the relative uniformity in indices are examined. It is shown that the coordinated index provided by the phrase is the more meaningful and discriminating.

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Automatic Failure Recovery in a Digital Data Processing System *by R. H. Doyle, R. A. Meyer, and R. P. Pedowitz, p. 2.* This paper describes a program which will enable a complex digital data processing system to give "first aid" to itself. Ordinarily, when an error occurs during system operations, the computer must be stopped for corrective maintenance. The FIX program, however, automatically compensates for computer malfunctions so that recovery from errors may be effected with a negligible loss of operational time. Some equipment features used by the FIX program are briefly outlined prior to a detailed discussion of the structure and function of the program itself. In its initial application in the SAGE system, FIX provided automatic recovery from more than 90% of all failures occurring during the period studied.

Diffusion Attenuation, Part I *by J. A. Swanson, p. 13.* Perturbation methods are applied to the problem of calculating the attenuation of signals consisting of compensated space charges moving in an electric field of general, but prescribed, form. Asymptotic formulas for attenuation and phase shift are derived which apply when the diffusion currents giving rise to attenuation are small compared to the field-induced currents. Alternate expansions of the continuity equation, e.g., in terms of the frequency, are discussed in a mathematical appendix.

Diffusion Attenuation, Part II *by J. A. Swanson and K. Y. Sih, p. 18.* The amount of diffusion attenuation has been computed as a function of frequency for the case of uniform electric field. Application to drift transistors is discussed.

On the Mathematical Theory of Error-Correcting Codes *by H. S. Shapiro and D. L. Slotnick, p. 25.* Hamming considered the problem of efficient, faultless transmission of binary data over a noisy channel. For a channel which corrupts no more than one binary digit in each sequence of length n, he constructed alphabets, the so-called Hamming codes, which permit error-free signalling. The authors study the analogous problem for channels which can corrupt a greater number of digits. Non-binary channels are also studied, and analogues of the Hamming codes are constructed. It is perhaps of interest that some of the techniques employed derive from algebraic and analytic number theory, mathematical disciplines not generally associated with the type of applied problems considered in this paper.

The Thermal Equivalent Circuit of a Transistor *by P. R. Strickland, p. 35.* An exact electrical analogue is given for the thermal system between the collector junction and the constant-temperature environment of a transistor. For this circuit analogue, the voltage response to an applied current is equivalent to the temperature response of the collector junction to an applied-power dissipation. The objective of this paper is (1) to prove that this thermal equivalent circuit is entirely consistent with the rigorous, academic approach to the problem, which is to solve a boundary-value problem for heat flow in the transistor system; (2) to present an experimental method for obtaining the circuit parameters in the thermal equivalent circuit; and (3) to demonstrate the utility of the thermal equivalent circuit for the circuit designer and the transistor designer.

The Multipurpose Bias Device—Part II: The Efficiency of Logical Elements *by B. Dunham, D. Middleton, J. H. North, J. A. Sliter, and J. W. Weltzien, p. 46.* The efficiency of a logical element can be equated with the set of subfunctions it realizes upon biasing or duplication of inputs. Various classes of elements are considered, and optimum or near-optimum examples are presented. Some related areas of study are suggested.

An Analysis of Adequate Inventory Levels *by J. J. Sopka, p. 54.* An analytical procedure for determining adequate stock levels for an inventory system with random demand and replenishment functions is presented.

Two-Parameter Lifetime Distributions for Reliability Studies of Renewal Processes *by B. J. Flehinger and P. A. Lewis, p. 58.* Probability functions are defined for use in reliability studies of equipments which are maintained over a long period of time through replacement of components. These are: *lifetime distribution function, lifetime density function, probability of survival, hazard, expected number of replacements,* and *renewal rate.* Theoretical results of renewal theory are adapted to reliability studies of complex systems.

The "exponential law" is equivalent to the assumption that survival probability for any given time interval is independent of the age of a component at the beginning of the interval. It seems more realistic, however, to assume that this survival probability is a monotonically *decreasing* function of initial age, or, equivalently, that the hazard is a monotonically *increasing* function of the age of the component. Consequently, three two-parameter models of distribution functions, with the properties: (1) initial lifetime density greater than zero, and (2) monotonically increasing hazard, are proposed and discussed. The lifetime behavior associated with these models ranges from complete determinacy to complete randomness. An entropic measure of this randomness is introduced.

The expected number of replacements is numerically calculated and plotted as a function of time for several different parameter values in each model.

An Experimental Modulation-Demodulation Scheme for High-Speed Data Transmission *by E. Hopner, p. 74.* An experimental low-cost system was designed to determine speed and reliability limitations on transmitting binary data over private telephone lines. A brief review of alternative

approaches is given, with a description of the laboratory model. Performance of the equipment is reported with the reliabilities experienced at 600, 1000, 1600, and 2400 bits per second.

Application of Phase-Contrast Metallography in a Production Laboratory *by G. Koves, p. 85.*

Observations of Rotational Switching in Ferrites *by W. L. Shevel, Jr., p. 93.*

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Direct Measurement of the Angular Dependence of the Imaginary Part of the Atomic Scattering Factor of Germanium *by L. P. Hunter, p. 106.* In the dynamical theory of the anomalous transmission of x-rays through perfect thick crystals, the ratio of transmitted intensity to incident intensity depends upon $[1 - Kf_{Ge}'' (\theta_{hkl})/f_{Ge}'' (0°)]$ exponentially. Here K is the polarization factor and the $f_{Ge}'' (\theta_{hkl})$ and $f_{Ge}'' (0°)$ are the imaginary parts of the atomic scattering factors of germanium at the angle θ_{hkl} and 0°, respectively. This paper describes the measurement of the ratio $f_{Ge}'' (\theta_{hkl})/f_{Ge}'' (0°)$ for several different sets of planes in nearly perfect germanium crystals.

Finite Automata and Their Decision Problems *by M. O. Rabin and D. Scott, p. 114.* Finite automata are considered in this paper as instruments for classifying finite tapes. Each one-tape automaton defines a set of tapes, a two-tape automaton defines a set of pairs of tapes, et cetera. The structure of the defined sets is studied. Various generalizations of the notion of an automaton are introduced and their relation to the classical automata is determined. Some decision problems concerning automata are shown to be solvable by effective algorithms; others turn out to be unsolvable by algorithms.

Interatomic-Force Constants from a Central-Force Law *by H. Cole, p. 126.* Interatomic-force constants may be predicted from standard central-force laws using thermodynamic data. For the three cases where diffraction data are available (aluminum, copper, and iron) the predicted values agree within an order of magnitude for aluminum and iron, but differ strongly in the case of copper. It is suggested that Jacobsen's α_1, for copper, represents the strongest departure from a central-force model and should therefore be the most promising point for further theoretical work.

On the Transition from Superconducting to Normal Phase, Accounting for Latent Heat and Eddy Currents *by A. J. W. Duijvestijn, p. 132.* A rigorous solution is given for the superconducting transition of a semi-infinite slab held at a point below the critical temperature T_c when a constant magnetic field above the critical value H_∞ is applied. The solution accounts for both the absorption of latent heat and the dissipation of eddy-current heat during the transition. A numerical example is calculated for the case of constants close to those of tantalum.

Geometric Effects in the Superconducting Transition of Thin Films *by M. D. Reeber, p. 140.* A study is made of the effect of geometric factors and field orientation on the superconducting transition of bulk material whose dimensional ratios are comparable to those of thin evaporated films. An expression is derived for an effective demagnetizing coefficient in the direction of the applied field for an elliptic cylindrical superconductor, and it is shown that this deviates from 1 by quantities of the order of 10^{-2} or smaller for experimentally realizable conditions with typical films. These small coefficients give rise to surface fields sufficiently large for transition to the intermediate state. The shape of the transition for various field orientations has been obtained experimentally, and these curves are analyzed qualitatively on the basis of Landau's and Andrew's theory of the intermediate state. For temperatures below the transition point, and in the absence of fields other than the earth's magnetic field, the possibility that these films are in the intermediate state is explored.

Computation of Sin N, Cos N, and $\sqrt[4]{N}$ Using an Electronic Computer *by E. G. Kogbetliantz, p. 147.* Rational Padé approximations to Sin N in the interval $0 \le N \le 41\pi/256$ and to Cos N in $0 \le N \le 87\pi/256$ allow the computation of both functions in $0 \le N \le \pi/2$ with the first ten correct significant digits in four multiplications and divisions only. If the infinite range $0 \le N < \infty$ is considered, one more multiplication reduces it to the range $0 \le N \le \pi/2$ so that the total number of operations is five. The method is flexible and gives any desired accuracy. Thus if eighteen first correct significant digits are required, they are obtained in seven operations for any N in $(0, \infty)$.

The same method applied to $\sqrt{N}$ and $\sqrt[3]{N}$ yields a very accurate first guess which then is improved by Newton's method. For the radicals $\sqrt[m]{N}$ with $m > 4$, Newton's method is too slow, and rational Padé approximations studied in this paper yield better subroutines.

Microwave Resonance in Gadolinium-Iron Garnet Crystals *by W. V. Smith, J. Overmeyer, and B. A. Calhoun, p. 153.* Ferrimagnetic resonance has been observed in single crystals of gadolinium-iron garnet at 9479 and 23,725 mc. The resonance behavior is discussed in terms of a two-sublattice theory. The gadolinium g-factor is equal to 2.006 above − 90°C and increases at lower temperatures. The gadolinium ions contribute to the anisotropy below − 40°C. The assignment of separate damping constants to each sublattice explains the sharp variation in over-all damping with temperature near the compensation point.

On Codes for Checking Logical Operations *by W. W. Peterson and M. O. Rabin, p. 163.* Two types of codes for checking logical operations digit by digit on two vectors of

binary digits are studied. The first type attaches a check symbol to each vector of binary digits and requires that the check symbol for the logical function of two vectors can be determined from the check symbols of the two input vectors. The second type of coding is ordinary block coding into vectors of binary digits, with the added requirement that the coded vectors be processed digit by digit.

The constraints on the codes resulting from the assumptions for the coding system are studied by typical algebraic arguments. It is shown that for both types of coding and for all nontrivial logical functions of two variables, except "exclusive or" and its complement, there is no system of checking simpler than duplication. For "exclusive or" and its complement, group alphabets can be used, and for the block coding these are the only codes which can be used.

Extension of Moore-Shannon Model for Relay Circuits *by M. Kochen, p. 169.* The Moore-Shannon model for switching circuits is extended to show how the number of redundant relays needed to improve reliability depends on the logical function of the entire circuit. The reliabilities of AND, OR, and EXCLUSIVE-OR relay circuits are studied as a function of the number of relays, the network topology, and the distribution of inputs. For the case of intermittent failures, a procedure is developed for calculating the reliability of combinational switching circuits, defined as the probability that the circuit will function as specified, averaged over all possible inputs, and subject to the idealizing assumptions of the Moore-Shannon model. The redundancies required to achieve a specified increase in reliability, although considerably smaller than for alternative methods, are still enormous. It is shown that a good way to improve an AND circuit, for example, is to use a series-parallel network in which the number of parallel lines varies with the logarithm of the number of basic AND circuits connected in series to form each line.

Numerical Solution of Laplace's Equation, Given Cauchy Conditions *by I. Sugai, p. 187.*

A Cryogenic Oscillator *by G. B. Rosenberger, p. 189.*

Noise Theory for Hot Electrons *by P. J. Price, p. 191.*

Doubling the Efficiency of the Load-Sharing Matrix Switch *by M. P. Marcus, p. 194.*

Elementary Divisors of Normal Matrices *by P. Erdös, p. 197.*

The Reduction of Two-Way Automata to One-Way Automata *by J. C. Shepherdson, p. 198.*

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Some Studies in Machine Learning Using the Game of Checkers *by A. L. Samuel, p. 210.* Two machine-learning procedures have been investigated in some detail using the game of checkers. Enough work has been done to verify the fact that a computer can be programmed so that it will learn to play a better game of checkers than can be played by the person who wrote the program. Furthermore, it can learn to do this in a remarkably short period of time (8 or 10 hours of machine-playing time) when given only the rules of the game, a sense of direction, and a redundant and incomplete list of parameters which are thought to have something to do with the game, but whose correct signs and relative weights are unknown and unspecified. The principles of machine learning verified by these experiments are, of course, applicable to many other situations.

Some Properties of Experimental 1000-Mc Transistors *by R. F. Rutz and D. F. Singer, p. 230.* Experimental transistors designed to operate above 1000 Mc are described and measurements of their electrical parameters discussed. The design is a diffused-base drift transistor structure with minimized bulk resistances and junction capacitances. Measurements of the short-circuit current gain ($-h_{21p}$) with both emitter and collector reverse-biased, indicated that the passive circuit comprising extrinsic parameters only could produce a gain greater than unity. Interpretation of measurements using a simplified equivalent circuit shows that reduction of bulk resistances leads to an appreciable passive or feed-through current. An osciilator is described in which the transistors operated up to 1550 Mc.

A Gas Film Lubrication Study—Part I: Some Theoretical Analyses of Slider Bearings *by W. A. Gross, p. 237.* The Reynolds differential equation describing flow in a compressible lubricating film is developed. Important characteristics of such films are determined directly from the Reynolds Equation. Pressure, load, velocity, and geometry characteristics are presented for many compressible slider bearing films based upon computer solutions of a Reynolds difference equation as derived in Part II. Part III cites experimental verification of computer solutions and describes experimental techniques.

A Gas Film Lubrication Study—Part II: Numerical Solution of the Reynolds Equation for Finite Slider Bearings *by W. A. Michael, p. 256.* This paper presents a finite-difference technique for obtaining approximate numerical solutions to the Reynolds partial differential equation of gas film lubrication theory. A digital computer program is described, and discretization errors and stability of the difference equations are discussed.

A Gas Film Lubrication Study—Part III: Experimental Investigation of Pivoted Slider Bearings *by R. K. Brunner, J. M. Harker, K. E. Haughton, and A. G. Osterlund, p. 260.* The results of experimental measurements on pivoted slider bearings are presented, the experimental methods are described, and the experimental data are compared with data obtained from a numerical solution of the Reynolds differential equation for a compressible fluid.

Experiments on the Relation of the Operator to the Control Loop of an Airborne Digital Computer *by C. A. Bennett, p. 275.* Some laboratory experiments were performed over a period of three years to provide design information for digital computer systems for error correction in aircraft navigation. In a simulated digital control loop, the operator observed crosshair error and fed control signals to the computer. The studies showed relationships between recovery time and solution rate, transmission delays, hand-control sensitivity, sampling rate, and scanning rate.

A Learning Machine: Part II *by R. M. Friedberg, B. Dunham, and J. H. North, p. 282.* An effort is made to improve the performance of the learning machine described in Part I, and the over-all effect of various changes is considered. Comparative runs by machines without the scoring mechanism indicate that the grading of individual instructions can aid in the learning process. A related study is made in which automatic debugging of programs is taken as a special case of machine search. The ability to partition problems and to deal with parts in order of difficulty proves helpful.

Indexing and Control-Word Techniques *by G. A. Blaauw, p. 288.* In large-scale computers the details of data handling, such as indexing, transmission and ordering, may be performed either by programming or by built-in machine operations. An analysis of the most frequently performed functions justifies the expansion of single-valued index quantities to three-valued control words and the specification of built-in increment, count and refill operations to be used with these control words. STRETCH, the large-scale computer which is being developed by IBM for the Los Alamos Scientific Laboratory, provides these control-word functions for data-handling operations.

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Some New Aspects of Color Perception *by M. M. Woolfson, p. 312.* A mathematical analysis is made of Land's recent experiments which showed that fully colored pictures can be produced by a two-color projection system. Although Land's results apparently had been at variance with the classical theories of color perception, it has now been found possible to explain the experiments within the framework of those theories and in conjunction with well-known phenomena in the field of experimental psychology. The results are interpreted in terms of a mechanism of color transformation.

Algebraic Topological Methods for the Synthesis of Switching Systems, Part III: Minimization of Nonsingular Boolean Trees *by J. P. Roth and E. G. Wagner, p. 326.* An algorithm is given for solving a general problem in combinational switching-circuit minimization theory. The circuits considered consist of a disjunction (OR-ing together) of trees of any set of logical elements, with the restriction that in any given tree no input appears more than once. To each logical element is attached a positive cost. A method is presented for designing a minimum-cost circuit of this variety for any given logical function. Two parallel treatments are given, one viewing it as an abstract mathematical problem, the other considering it as an engineering problem.

Theory of a Fast-Switching Electron-Beam Frequency Divider *by N. M. Kroll and I. Palócz, p. 345.* A velocity-modulated electron-beam microwave tube is described which can be operated as a frequency divider. Its operation is analyzed in terms of velocity-modulation bunching theory, neglecting space-charge forces. Because of the existence of two stable states opposite in phase, such a divider can be advantageously employed in a microwave logical system. The transient behavior of the device is discussed, particularly with reference to the time required to switch the device from one of its stable states to the other. Factors involved in the minimization of this time interval are analyzed.

On the Reduction of Continuous Problems to Discrete Form *by J. Greenstadt, p. 355.* A continuous problem, defined as one involving derivatives or integrals, is to be reduced to a discrete problem, involving only algebraic or evaluative operations. An approach involving cells instead of points is taken, and the unknown function is approximated by functional representations, each associated with one cell and an associated set of parameters. Suitable operations are then defined, each associated with a particular cell. These operations remove the configuration coordinates from the problem, leaving only the parameters. Similar operations are defined which link the approximations in adjacent cells, and which translate certain interface conditions to relations between parameters associated with cells. The entire set of relations is then the equivalent of the usual difference equations.

A variational algorithm is introduced in order to circumvent certain difficulties associated with matching equations and unknowns. This also permits the convenient retention of certain "exact conditions" associated with the continuous problem. Some illustrative examples are given.

Esaki Tunneling *by P. J. Price and J. M. Radcliffe, p. 364.* Tunneling, between propagating electron states, at a semiconductor junction is discussed in terms of customary quantum transition theory for the matrix elements of the hamiltonian between the states representing reflection of an

electron (in either band) from the junction. The coordinate representation for the wavefunctions of these states is investigated, and tunneling probabilities (ratios of transmitted to incident current) are found for the "elastic" process proposed by Esaki and for the "phonon-assisted" processes. It appears that the tunneling may be described as taking place in a central region of the junction thinner than the space charge region. Current-voltage characteristics are calculated both for elastic and for phonon-assisted tunneling.

A 3000-Mc Lumped-Parameter Oscillator Using an Esaki Negative-Resistance Diode *by R. F. Rutz, p. 372.*

Millimicrosecond Magnetization Reversal in Thin Magnetic Films *by W. Dietrich and W. E. Proebster, p. 375.*

Germanium PNPN Thyratron *by M. Klein and A. P. Kordalewski, p. 377.*

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Toward Mechanical Mathematics *by H. Wang, p. 2.* Results are reported here of a rather successful attempt of proving all theorems, totalling near 400, of *Principia Mathematica* which are strictly in the realm of logic, viz., the restricted predicate calculus with equality. A number of other problems of the same type are discussed. It is suggested that the time is ripe for a new branch of applied logic which may be called "inferential" analysis, which treats proofs as numerical analysis does calculations. This discipline seems capable, in the not too remote future, of leading to machine proofs of difficult new theorems. An easier preparatory task is to use machines to formalize proofs of known theorems. This line of work may also lead to mechanical checks of new mathematical results comparable to the debugging of a program.

A Thermodynamic Treatment of Dilute Superconducting Alloys *by R. E. Jones, Jr., p. 23.* The effect of adding small concentrations of an impurity to a superconducting metal is analyzed by thermodynamic methods. Two possible types of variation of the Gibbs free energy with composition are then discussed, utilizing a number of simplifying assumptions. For the case in which alloys have a superconducting second-order transition, there is a long-range interaction among solute atoms, even in limits of high dilution.

A Proof Method for Quantification Theory: Its Justification and Realization *by P. C. Gilmore, p. 28.* A program is described which can provide a computer with quick logical facility for syllogisms and moderately more complicated sentences. The program realizes a method for proving that a sentence of quantification theory is logically true. The program, furthermore, provides a decision procedure over a subclass of the sentences of quantification theory. The subclass of sentences for which the program provides a decision procedure includes all syllogisms. Full justification of the method is given.

A program for the IBM 704 Data Processing Machine is outlined which realizes the method. Production runs of the program indicate that for a class of moderately complicated sentences the program can produce proofs in intervals ranging up to two minutes.

The Wave Equation in a Medium in Motion *by W. L. Miranker, p. 36.* A model for the transverse vibrations of a tape moving between a pair of pulleys is devised using a variational procedure. It is shown by means of energy-type integrals that the energy of that portion of the tape between the pulleys is not conserved, but that there is a periodic transfer of energy into and out of the system. The solution for the wave equation is then constructed by a method which makes use of functional equations. The solution is observed to be periodic in time, and a modal decomposition of it is derived. A solution is also derived for the case of forced vibrations at the pulleys, and a class of forcing vibrations which cause unbounded solutions as time increases is isolated. In an appendix, a boundary layer effect is considered which occurs when the velocity of the tape through the pulleys approaches the sound speed of the tape.

Design Methods for Maximum Minimum-Distance Error-Correcting Codes *by J. E. MacDonald, p. 43.* In error-correcting codes for combating noisy transmission channels, a central concept is the notion of minimum distance. If a code can be constructed with minimum distance between code points of $2m+1$, then any number of errors per code word which does not exceed m can be corrected, thus increasing the reliability of transmission above that to be expected with no redundancy in the code.

An upper bound on minimum distance is derived which depends on g (the number of code points or messages required) and n (the number of binary symbols per code point). This bound is complementary to a bound due to Hamming and uses an argument which is essentially due to Plotkin.

Construction methods are presented for codes which actually achieve the upper bound on minimum distance for any g and an infinite class of integers n which depend on g. Sixteen code types are described: three for $g = 2h-1$, six for $g = 2h$, and seven for $g = 2^k$.

A New Group of Codes for Correction of Dependent Errors in Data Transmission *by C. M. Melas, p. 58.* Multiple related errors of any configuration can be automatically corrected by a class of codes having the property of using two groups of parity bits, one defining the error pattern, the other determining the location of the errors within the block.

In particular, error bursts can be corrected with a minimum amount of redundancy. Because each parity-bit group is derived by using maximum-length shift-register sequences, rather than by storing a decoding table, the implementation of these codes is relatively simple, as shown in an example of a three-bit-wide burst-correcting code. An example is given of an application of these codes in a data transmission system where only an even number of bits is likely to be corrupted by a noise burst.

Information Theoretical Analysis of Multivariate Correlation *by S. Watanabe, p. 66.* A set λ of stochastic variables, $y_1, y_2, \ldots, y_n$, is grouped into subsets, $\mu_1, \mu_2, \ldots, \mu_k$. The correlation existing in λ with respect to the μ's is adequately expressed by

$$C = \sum_{i=1}^{k} S(\mu_i) - S(\lambda) \geq 0,$$

where $S(\nu)$ is the entropy function defined with reference to the variables y in subset ν. For a given λ, C becomes maximum when each μ_i consists of only one variable, $(n = k)$. The value C is then called *the total correlation in* λ, $C_{tot}(\lambda)$. The present paper gives various theorems, according to which $C_{tot}(\lambda)$ can be decomposed in terms of the partial correlations existing in subsets of λ, and of quantities derivable therefrom. The information-theoretical meaning of each decomposition is carefully explained. As illustrations, two problems are discussed at the end of the paper: (1) redundancy in geometrical figures in pattern recognition, and (2) randomization effect of shuffling cards marked "zero" or "one."

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Foreword *by E. W. Pugh, p. 94.*

Domain Walls in Thin Ni-Fe Films *by S. Methfessel, S. Middelhoek, and H. Thomas, p. 96.* Observations of domain walls in Ni-Fe films as a function of thickness demonstrate the strong influence of magnetic stray fields on the wall structure, hence on the coercivity for wall motion. In order to reduce the stray-field energy, the Bloch walls in films thicker than 1000 Å are subdivided into sections with alternating polarity which are separated by Bloch lines. In thinner films, the domain walls are of the Néel type. The position of Bloch lines in such walls is indicated by crosswalls. The motion of Bloch lines in an applied field can be observed particularly easily on scratches in negative magnetostrictive material; such scratches display properties corresponding to Néel walls. Crosswalls are also present at the ends of domains and around holes in the film material. A crosswall is distinguished from ordinary domain walls by the continuous change of the angle of magnetization along both sides of it.

Measurement of Magnetic-Field Attenuation by Thin Superconducting Films *by E. Erlbach, R. L. Garwin, and M. P. Sarachik, p. 107.* The dependence of the field attenuation on temperature and superimposed dc magnetic field is measured with a sensitive rf bridge. It is shown theoretically that the penetration depth λ can be derived from the attenuation measurements, and the experiment therefore yields λ as a function of temperature and dc magnetic field. Changes in λ can be detected to an accuracy of $\pm 0.03\%$. Preliminary data on the temperature dependence of λ for lead are compared with the predictions of the Bardeen-Cooper-Schrieffer theory and are shown to be consistent with an energy gap between 4.9 kT_c and 5.4 kT_c at 0K. Detailed descriptions are given of the apparatus and of the preparation of the samples.

Magnetic Anisotropy in Single-Crystal Thin Films *by E. L. Boyd, p. 116.* Thin, single-crystal films of Ni, Fe, Ni-Fe and Ni-Co have been grown by vacuum deposition onto heated rock salt. The cubic crystalline anisotropy constant, K_1, of these films has been measured at room temperature by a torque method. In the case of the Ni-Fe alloys, K_1 was found to be the same for thin films as for bulk materials of the same composition. The measured anisotropy in the Ni-Co films differs quantitatively but has the same qualitative variation with composition as is reported for bulk crystals. The results of one magnetic annealing experiment on a 75% Ni - 25% Fe film lends support to the short-range ordering model of uniaxial anisotropy in alloys. Pure nickel films exhibit a pronounced uniaxial anisotropy superimposed on the crystalline anisotropy. This uniaxial term disappears after the film is removed from the substrate, indicating that its origin is in an anisotropic stress in the deposited film.

Analysis of the Residual Gases in Several Types of High-Vacuum Evaporators *by H. L. Caswell, p. 130.* A mass spectrometer study is made of the residual gases in several types of vacuum evaporators ranging from oil-diffusion-pumped, conventional systems to an oil-free, ultra-high-vacuum chamber. Partial pressures of water vapor, hydrogen, carbon monoxide, carbon dioxide, nitrogen, oxygen, argon and hydrocarbon vapors varied appreciably in the evaporators studied.

The performance of a conventional system was improved by using special low-vapor-pressure gasket materials to minimize hydrocarbon contamination, a liquid-nitrogen trap to reduce water vapor, titanium gettering for oxygen and nickel-iron gettering for hydrogen. For thin-film deposition, the importance of thoroughly outgassing the source materials is pointed out.

Electrical Properties of Thin-Film Semiconductors *by F. S. Ham and D. C. Mattis, p. 143.* The theory of the electrical properties of metal films as given by Fuchs and Sondheimer is extended to nondegenerate semiconductors with ellipsoidal energy surfaces. A change of variables reduces the problem to a simpler one with spherical energy surfaces but with electric and magnetic fields which are tilted with respect to the film. This is solved to first order in the applied fields. The effective mobility and Hall coefficient vary with film thickness much as for a metal but show an anisotropy with film orientation, even for cubic crystals. Anisotropy is observed for both diffuse and specular surface scattering and for surface channels as well as films, and it provides a means of measuring the effective mass ratio of the carriers.

Anisotropic Conduction in Solids Near Surfaces *by P. J. Price, p. 152.* A reduction in the electrical conductivity of a solid results from "diffuse" reflection of electrons from the surfaces. The effect occurs for specular reflection also, if the operative electron-energy surfaces are not spherical. A theory of the latter case is given here. The average conductivity of a thin crystal tends to a finite limit (rather than zero) as the thickness tends to zero. The Hall effect for the same circumstances is also treated.

Size Effects for Conduction in Thin Bismuth Crystals *by A. N. Friedman and S. H. Koenig, p. 158.* The size dependence of the electrical conductivity, and preliminary results for galvanomagnetic effects, in thin, single crystals of high-purity bismuth at 4.2K are reported for a range of thicknesses comparable to the electron mean free path. The results, when interpreted according to the theory of Ham and Mattis and of Price (in the accompanying papers), show that the scattering of electrons by the surface is specular, and confirm the novel predictions of the theory for the case of specular reflection and anisotropic surfaces of constant energy.

Angle-of-Incidence Anisotropy in Evaporated Nickel-Iron Films *by E. W. Pugh, E. L. Boyd, and J. F. Freedman, p. 163.* The magnetic anisotropies of iron, nickel, and permalloy films, evaporated onto glass substrates at various incident angles and substrate temperatures, have been measured by a torque method. For all compositions, the largest absolute value for the magnetic anisotropy occurs at the largest incident angle and lowest substrate temperature. A detailed calculation of the anisotropy resulting from a [111] fiber axis is found to fail to agree with the experimental results either in order of magnitude or in direction of the easy axis. The change in the magnetic anisotropies of films after removal from substrates is small enough that macroscopic stress cannot be the source of the anisotropy. A difference in electrical resistance parallel and perpendicular to a direction defined by the vapor stream during deposition is found to vary qualitatively very much like the magnetic anisotropy, both with film composition and incident angle. It is concluded that deposition at an angle of incidence produces an anisotropy in structural imperfections, which are interpreted in terms of shape and surface magnetic anisotropies as well as magnetostrictive effects.

Superconducting Tin Films of Low Residual Resistivity *by G. J. Kahan, R. B. DeLano, Jr., A. E. Brennemann, and R. T. C. Tsui, p. 173.* Evaporated tin films of low residual resistivity have been produced by using very high deposition rates in a conventional vacuum system. The substrates were cooled with liquid nitrogen. After the film edges are removed by mechanical trimming or chemical etching, these films show sharp magnetic and temperature transitions from the superconducting to the normal state, a critical field - temperature characteristic which is close to a modified version of the London theory, a transition temperature very close to the value of bulk tin, and a reversible resistance - critical current characteristic. These characteristics are compared with those of films deposited on substrates at room temperature using low deposition rates. Evidence is presented to indicate that the edge effect in the temperature transition of films is caused by a concentration of impurities in the edges. The low-temperature mean free path, rather than the resistivity ratio, is suggested as a figure of merit for estimating film purity because the size effect limits the resistivity ratio for thin films.

On the Influence of Aggregation on the Magnetic Phase Transition of Evaporated Superconducting Thin Films *by M. E. Behrndt, R. H. Blumberg, and G. R. Giedd, p. 184.* An investigation was made of the magnetic phase transition of thin, superconducting Sn films. In evaporated films, because of the sloping edges, broad magnetic field transitions are generally found. This paper shows that such "penumbra" effects can be eliminated by raising the temperature of the substrate during evaporation. The lack of penumbra effect was due to the aggregation of the film. The transition curves of such films displayed hysteresis.

Nanosecond Switching in Thin Magnetic Films *by W. Dietrich, W. E. Proebster, and P. Wolf, p. 189.* A special pulse equipment including a pulse-sampling oscilloscope with an over-all response time of 0.35 nanosecond (10^{-9} sec) for the observation of the nanosecond flux change in thin permalloy films is described. Film switching signals as short as 1 nanosecond have been obtained and are discussed with respect to the underlying processes. Inverse switching time versus driving-field curves have been plotted for films of different thicknesses. They show that thinner films switch faster than thicker ones. The slopes of these curves have characteristic values in the nanosecond region of about 10^8 per oersted-second. Coherent rotation and oscillation of the magnetization have been clearly detected by picking up the flux change transverse to the driving field.

The Variation of Cryotron Current Amplification Factor with Temperature *by A. E. Brennemann, p. 197.*

The Influence of Edge Effects on Domain Structure and Coercive Force of Circular Nickel-Iron Films *by M. Beckerman and K. H. Behrndt, p. 198.*

A New Electron Mirror Design *by J. D. Kuehler, p. 202.*

Measurement of Crystallite Size and Strain of Electroplated Films *by R. S. Smith, p. 205.*

Information-Theoretical Aspects of Inductive and Deductive Inference *by S. Watanabe, p. 208.* By a straightforward application of Bayes' theorem of probability, the behavior is discussed of the credibilities (inductive probabilities) of competing hypotheses as functions of an increasing body of relevant empirical data. It is shown how the effect of a priori credibilities persists in the evaluation of credibilities in general, except in the important limiting cases investigated. An "inverse H-theorem" is mathematically demonstrated, according to which the entropy function defined in terms of the credibilities shows a net decrease in time. This decrease is not necessarily monotonous in an individual case, but is monotonous in the "expected" behavior of the inductive entropy function. Three machine-simulation experiments of inductive inference on the IBM 704 are described. The first two concern the classical problem of guessing the ratio of white and black balls in an urn. The third experiment

concerns guessing a hidden pattern obeyed by a sequence of binary numbers.

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Foreword: Vapor Growth *by G. R. Gunther-Mohr, p. 247.*

Epitaxial Vapor Growth of Ge Single Crystals in a Closed-Cycle Process *by J. C. Marinace, p. 248.* The Ge-I_2 disproportionation reaction in a sealed tube will deposit Ge epitaxially upon Ge seeds at a typical rate of 10μ/hr at a typical temperature of 400°C. Dislocations are of the same kind and approximate concentrations as observed in ordinary melt-grown Ge. Chemical purity is comparable to the best melt-grown Ge. The fraction of donors transferred from the source material to the deposited material is nearly unity over a wide range of concentrations, while the fraction of acceptors transferred is considerably less than unity. However, either *n*-type or *p*-type Ge can be deposited, and by using two sources within the same tube alternating layers can be obtained.

Electrical Properties of Vapor-Grown Ge Junctions *by M. J. O'Rourke, J. C. Marinace, R. L. Anderson, and W. H. White, p. 256.* A method of fabricating *p-n* junctions and *p-n* junction devices by a closed-cycle iodide vapor-growth process is described. The electrical characteristics of junctions made by alternately depositing *p*-type and *n*-type germanium onto a germanium substrate compare favorably with those fabricated by other means. Device arrays, such as diode matrices, and multijunction structures have been made by this process. If sufficient control can be achieved, devices having a wide range of impurity distributions and geometric configurations will be possible.

A Vapor-Grown Variable Capacitance Diode *by R. L. Anderson and M. J. O'Rourke, p. 264.* Germanium *p-n* junctions have been made which have a large fractional variation of capacitance with voltage and which have promise of being operable at high frequencies. These diodes are produced by a vapor-growth process in which the doping is switched from *n*-type to *p*-type during growth. Capacitances which vary as the reciprocal of voltage over a considerable range have been observed.

This capacitance variation corresponds to a net donor concentration which decreases from its value at the junction approximately as the reciprocal of distance from the junction. At a position corresponding roughly to the edge of the transition region at breakdown, the net donor concentration abruptly increases. This rapid variation of capacitance with voltage and the low series resistance resulting from the discontinuity in doping level should result in high-frequency diodes, if the magnitude of the discontinuity can be increased sufficiently.

Radiotracer Studies of the Incorporation of Iodine into Vapor-Grown Ge *by W. E. Baker and D. M. J. Compton, p. 269.* Measurements of the incorporation of iodine into single crystals of Ge grown by the disproportionation of GeI_2 have been made using I^{131} as a radioactive tracer. The results show that I is not likely to be a hindrance to device use of this material since the amount incorporated is moderately low ($10^{14} - 10^{15}$ atoms/cm^3), and does not appear to be correlated with electrical effects. It does not diffuse appreciably ($D_{875°} < 10^{-13}$ cm^2/sec). No excess is found at an all-deposited *p-n* junction. The concentration of I incorporated appears to decrease with increasing temperature, to be independent of growth rate on a (111) orientation of the seed, but to vary by a factor of up to 50 from one orientation to another. It is deduced that the I is incorporated by a mechanism intimately connected with the crystal growth.

Incorporation of As into Vapor-Grown Ge *by W. E. Baker and D. M. J. Compton, p. 275.* The incorporation of arsenic into single-crystal germanium grown by the disproportionation of GeI_2 was studied using As^{76} as a radioactive tracer, and using measurements of the Hall effect. The deposition was carried out in a sealed tube using as source material a single crystal of Ge doped to 2.5×10^{19} atoms/cm^3 with As. It was found that all the As incorporated into the vapor-grown Ge was electrically active, at least for material grown on a (211) Ge seed. The concentration of As in the deposited Ge was lower than that in the source, and appeared to depend on the crystallographic orientation of the growing face.

Tunnel Diodes by Vapor Growth of Ge on Ge and on GaAs *by J. C. Marinace, p. 280.*

Germanium - Gallium Arsenide Heterojunctions *by R. L. Anderson, p. 283.*

Epitaxial Growth of Silicon *by E. S. Wajda, B. W. Kippenhan, and W. H. White, p. 288.*

Incorporation of Au into Vapor-Grown Ge *by W. E. Baker and D. M. J. Compton, p. 296.*

Impurity Introduction during Epitaxial Growth of Silicon *by R. Glang and B. W. Kippenhan, p. 299.*

Dislocation Content in Epitaxially Vapor-Grown Ge Crystals *by H. S. Ingham, Jr. and P. J. McDade, p. 302.*

Physical versus Logical Coupling in Memory Systems *by J. A. Swanson, p. 305.* A memory system consisting of bistable static dissipationless units such as ferrites, ferroelectrics, or cryotrons is considered. For a given amount of physical material the memory capacity may be increased by using small volumes of the bistable material for each bit. If made sufficiently small, however, the individual bits will become unreliable because of the influence of thermal agitation and quantum-mechanical tunneling processes. Some

unreliability can be tolerated, since it can be compensated by redundancy. The optimum size of the individual bit, for maximum information storage, is evaluated. If thermal agitation is the prime source of errors, then the optimum-sized bit involves typically less than 100 of the independent cooperating units (electron spins, dipoles, et cetera) which cause the bistability. The maximization process concerns itself only with the preservation of information and not with possible methods of access to the individual bit. In particular, the maximization process neglects complications in the coding equipment needed to read in and out of memory.

Synthesis of a Communication Net *by R. T. Chien, p. 311.* A systematic method is given for the realization of communication nets from their terminal capacity matrices. It is shown that this procedure results in a net whose total branch capacity is minimum for all nets satisfying the same terminal capacity matrix. It is also shown that when the terminal capacity matrix is indeterminate, then, for a given total branch capacity, the total terminal capacity is highest when all terminal capacities are made equal.

Synthesis of Switching Functions by Linear Graph Theory *by W. Mayeda, p. 321.* Techniques of linear graph theory are applied to the study of switching networks. The first part treats the relationships among paths and circuits in a graph which will give a simple method of analyzing switching networks. The necessary conditions are given for the realizability of switching networks consisting of the specified elements. The second part is the synthesis which is accomplished by the use of the decomposition of cut-set matrices.

Error Correcting Codes for Correcting Bursts of Errors *by J. E. Meggitt, p. 329.* It is observed that the codes of Abramson, Melas and others are essentially described by the characteristic equation that a certain matrix satisfies. Consequently it is found that transformations of these codes are possible provided that the characteristic equation is preserved. These transformations may then be exploited to produce codes that have a simple implementation and, in fact, a general method is indicated by which any code may be implemented when the characteristic equation is known.

A Character-Recognition Study *by W. E. Dickinson, p. 335.* A study of the single-gap-scan approach to character recognition, using an IBM 650 for simulation, is reported. Ten specially designed digits were used in this study. Character recognition is discussed in terms of some simple concepts from n-dimensional geometry. The main contribution is an effective method for using a computer to aid in the design of the type font. This procedure is a natural development of the vector approach. Experimental results show the sensitivity of the system to phasing. An expression is given for a "quality factor." The relationship of this factor to errors and to ink density is illustrated.

On Dimensional Analysis *by R. E. Thun, p. 349.* The dimensions of physical quantities q are interpreted as vectors

$$q_i(\gamma_{i1}, \gamma_{i2}, \ldots, \gamma_{in}) \equiv \gamma_{i1}b_1 + \gamma_{i2}b_2 + \ldots + \gamma_{in}b_n ,$$

where the basic elements b_j generating the vector space represent the basic quantities of the dimensional system and the coefficients γ_{ij} are defined by

$$q_i = \prod_{j=1}^{n} b_j^{\gamma_{ij}} .$$

This interpretation permits the application of the theorems on vector spaces to dimensional analysis. Some results of this approach are simplified rules for the transformation of dimension and unit systems and a physically more transparent derivation of a complete set of dimensionless products by a transformation of bases. The new notation yields a sequential order of physical equations which may lead to a dimensional analysis based on appropriately selected equation groups.

Note on Perturbation of a Uniform Magnetic Field by a Cube of Magnetic Material *by F. Partovi, p. 357.*

Space-Charge-Limited Currents in Resin Films *by R. E. McCurry and R. M. Schaffert, p. 359.*

A Cyclic Code for Double Error Correction *by C. M. Melas, p. 364.*

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Fourier Analysis of the Motion of a Hydraulically Controlled Piston *by H. J. Greenberg, p. 378.* The problem is considered of the motion of a free piston in a finite pipe filled with a compressible liquid and subject to a step in pressure introduced from the two ends. The treatment is in one dimension using the linearized wave equation for the density disturbance and the linearized boundary conditions. A generalized Fourier series expansion leads to the solution of the problem. The mathematical analysis is complicated first by the presence of the interior boundary conditions which lead to a system of discontinuous eigenfunctions, and second, by the step pressure input which results in reflected discontinuities. By studying the properties of the eigenfunctions from a variational characterization, the formal expansions used are established rigorously. The motion of the piston is determined as a function of the input parameters, and the maximum piston excursion and the associated time are tabulated numerically over the ranges of interest of these parameters.

Shock Waves in Nonlinear Transmission Lines and Their Effect on Parametric Amplification *by R. Landauer, p. 391.* The propagation of a periodic signal on a transmission line

with a nonlinearity in the distributed capacitance is examined. The signal is deformed during its propagation and electromagnetic shock waves are generated. It is pointed out that the shock wave will form in a distance which is short for any parametric amplification purposes. The subsequent growth of the shock and its decay, due to the inevitable dissipation associated with a shock, are analyzed assuming that the capacitance variations are small compared to the total capacitance. The propagation of a small deviation from a signal which is perfectly periodic in time is also examined, and it is shown that the small deviation may spread out in time but cannot be changed in its sign. This result was invoked in an earlier paper demonstrating the impossibility of parametric amplification on dispersionless nonlinear lines.

On the Switching Time of Subharmonic Oscillators *by A. H. Nethercot, Jr., p. 402.* The time necessary to change the phase of an idealized subharmonic parametric oscillator from one value to a value differing by 180° is calculated for various values of pump power and switching power. Several conclusions are drawn from the results.

A Duality Theorem for Convex Programs *by W. S. Dorn, p. 407.* A proof is given for a duality theorem for a class of convex programs, i.e., constrained minimization of convex functions. A simple example is included.

A Class of Optimal Noiseless Load-Sharing Matrix Switches *by R. T. Chien, p. 414.*

New Developments in Load-Sharing Matrix Switches *by G. Constantine, Jr., p. 418.*

High-Speed Counter Requiring No Carry Propagation *by W. N. Carroll, p. 423.*

Increasing the Brightness-Voltage Nonlinearity of Electroluminescent Devices *by J. A. O'Connell and B. Narken, p. 426.*

Determining Component Variation for Gradual Transition between Dissimilar Impedances *by C. Becker, C. M. Bruen, and R. B. Turner, p. 430.*

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Foreword: Combinatorial Problems *by A. W. Tucker, p. 454.*

Traces, Term Ranks, Widths and Heights *by D. R. Fulkerson and H. J. Ryser, p. 455.* The notions of widths and heights of (0, 1)-matrices are discussed in the general setting of known results concerning traces and term ranks. Proofs are omitted throughout.

Automorphisms of Steiner Triple Systems *by M. Hall, Jr., p. 460.* This paper treats the following problem in combinatorial analysis: Find an incomplete balanced block design D with parameters b, v, r, k, and $\lambda = 1$, possessing an automorphism group G which is doubly transitive on the elements of D and such that the subgroup H of G fixing all the elements of a block is transitive on the remaining elements. Also find transitive extensions of such groups G. If the block design is a finite projective plane, the plane is necessarily Desarguesian. Thus, these properties of the automorphism group may be considered as a "Desarguesian" property of the designs.

This paper considers the case in which D is a Steiner triple system. The main result is that a "Desarguesian" Steiner triple system is either 1) a projective geometry over $GF(2)$ or 2) an affine geometry over $GF(3)$. Two intermediate results are of interest: 1) A Steiner triple system has for each element an involution fixing only this element, if and only if every triangle generates an $S(9)$, a Steiner triple system with 9 elements; 2) if a Steiner triple system has for each triple an involution fixing only the elements of this triple, then every triangle generates an $S(7)$ or an $S(9)$.

The Enumeration of Trees by Height and Diameter *by J. Riordan, p. 473.* The enumeration of trees which was begun by Harary and Prins, is simplified and elaborated in the interest of obtaining reliable numerical results. Height is a characteristic of a rooted tree, the length in lines of the longest path from the root, while the *diameter* of a (free) tree is the length of the longest path joining two endpoints. The most general enumerations given are for the case where a fixed number of the points of the trees are labeled with distinct labels, which puts in one setting the classical contrast of all points alike and all points unlike. The numerical tables given extend to trees with 20 points, all alike, and to trees with 10 points, all unlike.

Maximal Paths on Rectangular Boards *by R. E. Miller and J. L. Selfridge, p. 479.* A combinatorial approach is made to the problem of obtaining a path on a rectangular board of m by n squares with both terminals at the edges of the board. A square is said to be *covered* when the path enters one edge and leaves an adjacent edge. All other squares are said to be *missed*. Maximal paths are found, i.e., those which cover a maximum number of squares. For $m = n$, $m-2$ squares are missed when m is even, and $m-1$ squares are missed when m is odd. For $m < n$, $m-2$ squares are missed if m is even, and $n-2$ squares are missed if m is odd. The method of proof for m and n even is quite different from that for m or n odd. Certain properties of terminal positions, path length, types of missed squares, and unique paths are also investigated. The dependence of the results on the parity of m and n is again very striking.

On the Exceptional Case in a Characterization of the Arcs of a Complete Graph *by A. J. Hoffman, p. 487.* It is known that a certain simple set of properties characterize the relationship of adjacency of the $n(n-1)/2$ arcs of the complete

graph of order n, when $n \neq 8$, and that these properties are not a sufficient characterization when $n = 8$ (see [1], [2], [3], [4], and [7]). The present paper describes a method for enumerating all counter-examples when $n = 8$.

On Moore Graphs with Diameters 2 and 3 *by A. J. Hoffman and R. R. Singleton, p. 497.* This note treats the existence of connected, undirected graphs homogeneous of degree d and of diameter k, having a number of nodes which is maximal according to a certain definition. For $k = 2$ unique graphs exist for $d = 2, 3, 7$ and possibly for $d = 57$ (which is undecided), but for no other degree. For $k = 3$ a graph exists only for $d = 2$. The proof exploits the characteristic roots and vectors of the adjacency matrix (and its principal submatrices) of the graph.

Inductive Proof of the Simplex Method *by G. B. Dantzig, p. 505.* Instead of the customary proof of the existence of an optimal basis in the simplex method based on perturbation of the constant terms, this paper gives a new proof based on induction. From a pedagogical point of view it permits an earlier and more elementary proof of the fundamental duality theorem via the simplex method. Specifically we shall show that there exists a finite chain of feasible basis changes, which results in either an optimal feasible solution or in an infinite class of feasible solutions, such that the objective form tends to minus infinity.

Solving a Matrix Game by Linear Programming *by A. W. Tucker, p. 507.* This paper presents (1) a new characterization, via linear programming, of extreme optimal strategies of a matrix game and (2) a simple direct procedure for computing them. The first pertains to the neat formulas of L. S. Shapley and R. N. Snow for a "basic solution", and the second to the highly effective "simplex method" of G. B. Dantzig. Both are related to the author's "combinational equivalence" of matrices, the first through an optimal block-pivot transformation and the second through a suitably chosen succession of elementary pivot steps.

Some Combinatorial Lemmas in Topology *by H. W. Kuhn, p. 518.* For many years it has been known that a combinatorial result, called the Sperner Lemma, provides an elegant proof of the Brouwer Fixed Point Theorem. Although the proof is elementary, its complete formal exposition depends upon the somewhat complicated operation of subdividing a simplex. Also, the proof does not show whether the Sperner Lemma can be derived from the Brouwer Fixed Point Theorem.

This central result of this paper is a combinatorial proposition, analogous to the Sperner Lemma, and applying to the n-cube, for which subdivision is a trivial operation. This Cubical Sperner Lemma follows immediately from the Brouwer Fixed Point Theorem and thus opens the possibility of other applications of topology to combinatorial problems. The question of such a topological proof is raised for another cubical analogue of the Sperner Lemma, due to Ky Fan, and for the Tucker Lemma, which is related to the antipodal point theorems. The Cubical Sperner Lemma of this paper implies the Tucker Lemma in 2-dimensions; this suggests that other connections joining these combinatorial results remain to be discovered.

Minimal Complete Relay Decoding Networks *by E. F. Moore, p. 525.* The standard relay-contact-tree network has been used extensively for many years. If n is the number of relays involved, it has always been assumed that the $2(2^n-1)$ contacts used in the standard tree network is the smallest possible number of contacts with which such a network could be made. This paper proves that this is true, provided no sneak paths are allowed. This is in contrast to the result obtained by Lupanov, who showed that when n is five or more it is possible to save contacts below the usual number by permitting sneak paths.

This paper proves further theorems about any network which satisfies the same specifications as an n-relay tree without sneak circuits, and which is built with the minimal number of contacts. In particular, these theorems characterize such a network well enough that it can be shown to be one of the standard forms of relay tree network.

A Bound for Error-Correcting Codes *by J. H. Griesmer, p. 532.* This paper gives two new bounds for the code word length n which is required to obtain a binary group code of order 2^k with mutual distance d between code words. These bounds are compared with previously known bounds, and are shown to improve upon them for certain ranges of k and d. Values of k and d are given for which one of these bounds can actually be achieved; in such cases, the structure of the resulting codes is shown to satisfy a certain condition.

Minimization over Boolean Trees *by J. P. Roth, p. 543.* An algorithm is provided for what might be termed the general problem of logical design of circuits with one output and no feedback. Given a set ß of logical building blocks, each with a positive cost, each with one output, and given a Boolean function f the problem is to prescribe a Boolean tree constructed from the available set of building blocks which realizes f and which has a minimum cost. Actually a more general problem involving *don't care* conditions is treated. The cost of a Boolean tree shall be the sum of the costs of the building blocks of which it is composed. A special case of this problem is the classical logical problem of finding a functional expression for a given logical function which uses a minimum number of conjunctions, disjunctions and negations. Programmed on an IBM 704 computer, the algorithm is believed to be efficient on problems with eight or less variables.

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Periodic Solutions of the Wave Equation with a Nonlinear Interface Condition *by W. L. Miranker, p. 2.* In this paper we consider the problem of the voltage oscillations in a transmission line when a diode represented as a nonlinear capacitance is placed in shunt in that line. In particular we consider the response of this line to periodic driving voltages and study the periodic responses. This physical situation is shown to lead to the mathematical model of the wave equation in the voltage in a domain with an internal boundary (the interface), at which the voltage is required to satisfy a nonlinear jump condition. By an application of Gauss' theorem, the problem is reduced to a nonlinear difference-differential equation. In the case that the generator driving the line is matched to it, this family of equations reduces to a family of nonlinear differential equations. The paper is concerned with a study of the periodic solutions of these two classes of equations.

Theoretical Current Multiplication of a Cylindrical Hook Collector *by D. P. Kennedy, p. 25.* An analysis is given on the mechanisms of operation for a current-multiplying hook collector of cylindrical geometry. Mathematical equations are presented which establish the minority carrier transport efficiency within a cylindrical hook collector region; both surface and bulk recombination are assumed to be present. Also included in this analysis is the influence, upon current multiplication, of the factors determining minority carrier injection efficiency for a diffused hook emitter junction. Numerical evaluation of appropriate hook collector design equations are presented in graphical form throughout a range of geometrical parameters applicable to many practical situations.

Methods of Analysis of Circuit Transient Performance *by L. Hellerman and E. J. Skiko, p. 33.* This paper surveys some numerical methods applicable in obtaining the distribution of performance parameters associated with the transient behavior of switching circuits. The methods considered are: (1) *Monte Carlo,* in which sample circuits are simulated on the IBM 704 and their performance computed and tabulated. (2) *Parameter sensitivity methods,* including propagation of error, in which the first and second moments of the output distribution are estimated from parameter sensitivities; and a method using the total differential of the performance parameter to estimate the deviation of circuit behavior from its component deviations. (3) *A surface fitting method,* in which there is developed a formula for delay time in terms of circuit component values. Each method is used to determine the delay time of a simple system. Their merits and drawbacks are compared and discussed, and estimates are given of the IBM 704 machine time necessary for implementation on a ten-transistor switching circuit.

Analysis of a Constant-Input-Flow Hydraulic System *by S. C. Titcomb, p. 44.* An analysis of the system is discussed and its application to a paper form feeder carriage in a printer is described. A nonlinear differential equation is derived based on stated assumptions and lumped oil parameters. The equation is linearized and solutions for motor velocity and peak pressure, both versus time, are determined. The analytical results show the effect of system parameters on system acceleration, steady state volumetric efficiency, and peak pressure. A limited amount of experimental data has been collected and good correlation between theoretical prediction and experimental results for acceleration time and peak pressure has been achieved.

Solid-State Optical Maser Using Divalent Samarium in Calcium Fluoride *by P. P. Sorokin and M. J. Stevenson, p. 56.*

A Magnetic Associative Memory System *by W. L. McDermid and H. E. Petersen, p. 59.*

Acoustic-Mode Mobilities for "Split-p-Silicon" *by P. J. Price and Y.-H. Kao, p. 63.*

Hydrogen-like Impurity States in Axially Symmetric Crystals *by R. W. Keyes, p. 65.*

Card Capacitor—A Semipermanent, *Read Only* Memory *by H. R. Foglia, W. L. McDermid, and H. E. Petersen, p. 67.*

Safe X-Ray Shutter and Filter System *by F. Chambers, M. Okrasinski, and H. Cole, p. 69.*

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Table Look-up Procedures in Language Processing Part I: The Raw Text *by G. W. King, p. 86.* A method of addressing memories is described which is very powerful in the processing of natural languages, where the arithmetic or logical operations are either nonexistent or do not lend themselves to algorithmic description. The main feature is the guarantee of initiation of an exhaustive search for a linguistic word at a point just beyond the desired address. Sequential search backwards not only locates an address if it is there but also provides identification of a longest match first. The method is further extended to provide "conditional" addressing by prefixing subsequent addresses from information obtained in earlier searches.

Phase Reversal Data Transmission System for Switched and Private Telephone Line Applications *by E. Hopner, p. 93.* A phase reversal data transmission system is described, capable of operating at 2000 bauds over private telephone lines and at 1200 bauds over switched networks. The advantages and limitations of the system are discussed from a theoretical and practical standpoint. The clocking problem in data transmission is considered and several approaches are indicated. A summary is given of extensive field tests over

switched and private lines in Europe and on private (SAGE) lines in the U.S.

A Magnetic Associative Memory *by J. R. Kiseda, H. E. Petersen, W. C. Seelbach, and M. Teig, p. 106.* This paper describes a computer storage system in which data flows in and out of the memory on the basis of content rather than location (address). In addition, a small experimental model of this system is described, using ferrite cores as novel associative memory storage elements.

Acoustic-Mode Scattering of Holes *by M. Tiersten, p. 122.* Matrix elements are calculated for acoustic-mode scattering of holes in the valence band structure typified by germanium. Whitfield's generalization of the deformation potential theorem is used to calculate the electron-phonon interaction; his method is, however, extended to include the spin-lattice coupling. A general expression for the electron-phonon interaction matrix element is obtained, and calculations are presented for some special directions in **k**-space.

Analysis of a Basic Queuing Problem Arising in Computer Systems *by P. E. Boudreau and M. Kac, p. 132.* A model which describes a basic junction, or queuing structure, arising in a general computing system is subjected to a mathematical analysis. The results consist of several formulas describing the performance of various parts of the system. The feasibility in analyzing general queuing problems in this manner is stated, together with the results of a Monte Carlo simulation used for comparison purposes.

A Direct Digital Method of Power Spectrum Estimation *by P. D. Welch, p. 141.* This paper discusses a method of digital power spectrum estimation involving the direct combination of the sample time function with sines and cosines. This treatment is in contrast to the normal indirect digital method which proceeds through the intermediary of the autocovariance function. All the practical design details necessary for the planning of a spectral estimation program are treated.

The Dynamics of a Subharmonic Oscillator with Linear Dissipation *by G. J. Lasher, p. 157.* A mathematical analysis of the dynamic behavior of subharmonic oscillators (parametrons) is made assuming a nonlinear reactance but a linear dissipation or resistance. Simple equations of motion for the subharmonic and pump amplitudes are derived in the quasistatic, or high-Q, approximation. Numerical solutions are obtained for two cases. The first shows the subharmonic amplitude changing from a small value to its steady state value when a constant pump signal is applied. The second shows decay when the pump signal is removed.

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A 0.7-Microsecond Ferrite Core Memory *by W. H. Rhodes, L. A. Russell, F. E. Sakalay, and R. M. Whalen, p. 174.* The design and performance of a newly developed magnetic core memory is described. A two-dimensional array organization and partial switching of toroidal cores were employed in the design of this low-power, high-speed memory. The memory features a unique combination of a current-steering diode matrix and a load-sharing magnetic switch for an economical and high-performance drive system. The operating memory has a storage capacity of 73,728 bits and executes instructions reliably up to a repetition rate of 1.47 mc. The discussion will include a description of the organization, the series-parallel delay line clock, the control of critical timing pulses, and the actual measured performance.

Irreversibility and Heat Generation in the Computing Process *by R. Landauer, p. 183.* It is argued that computing machines inevitably involve devices which perform logical functions that do not have a single-valued inverse. This logical irreversibility is associated with physical irreversibility and requires a minimal heat generation, per machine cycle, typically of the order of kT for each irreversible function. This dissipation serves the purpose of standardizing signals and making them independent of their exact logical history. Two simple, but representative, models of bistable devices are subjected to a more detailed analysis of switching kinetics to yield the relationship between speed and energy dissipation, and to estimate the effects of errors induced by thermal fluctuations.

A Table Look-up Machine for Processing of Natural Languages *by J. L. Craft, E. H. Goldman, and W. B. Strohm, p. 192.* A table look-up machine based upon a photographic memory is being optimized for the processing of natural languages. It makes use of automatic retrieval of lexical information by means of novel addressing features which allow look-up of phrases regardless of length. Linguistic determinations made on the basis of the lexical information retrieved govern subsequent operations. In addition a sentence buffer holds a sentence long enough to make the backward and forward passes which will be required to make grammatical and contextual analyses.

An Approximate Method for Treating a Class of Multiqueue Problems *by M. A. Leibowitz, p. 204.* The following problem is considered: N queues of unrestricted length are served in cyclic order by a single server. Input to each queue is Poisson, the service time distribution may be arbitrary, and a finite time is required by the server to go from one queue to the next. Supposing that at any queue the server serves all units which he finds when he arrives, what is the probability p_n that in a stationary state he finds exactly n units? The method for solving this problem is based on the notion of a "self-consistent" probability distribution and is actually applicable to a general class of multiqueue situations of which the one considered here is typical.

Notes on Cumulative Photovoltages *by J. A. Swanson, p. 210.* It is reasoned that the large photovoltages observed by

Cheroff and Keller on ZnS crystals are theoretically plausible and can result from a wide class of different mechanisms. Conversely, the conditions under which a photoconductor with periodic inhomogeneities does not show a cumulative photovoltage are shown to be very restrictive and improbable. General theorems concerning the magnitude of the photovoltage are proved, and remarks are made on its directionality.

The Use of Radioisotopes to Determine the Chemistry of Solder Flux *by G. J. Sprokel, p. 218.* When rosin flux activated with amine halides is used in soldering printed circuit boards, metal halides are formed; these halides cannot be removed with organic solvents and thus may cause corrosion. The use of alkanol amines as solder fluxes has been investigated. After soldering, the flux can be removed by rinsing with water. Throughout this investigation radioisotopes were used to identify the compounds studied.

Bistable Systems of Differential Equations with Applications to Tunnel Diode Circuits *by J. K. Moser, p. 226.* A mathematical analysis is developed for nonlinear circuits which have at least two stable steady states, and therefore are of interest as computing or memory elements. Circuits containing one or two tunnel diodes will be analyzed in detail as applications of the theory.

The method is based on the study of certain "potential function" whose extrema are the steady states of the circuit and whose minima correspond to the stable switching states. This study leads to a qualitative description of all solutions in the large and results in quantitative restrictions on the parameters (*R, L, C* and nonlinear characteristics) which seem of practical importance.

Minimum Polarized Distance Codes *by M. P. Marcus, p. 241.* The choice of a code for a given application is influenced by many factors, such as economics, compatibility, and reliability. This paper is concerned solely with the reliability of codes, and shows how, for a given number of bits per character and a given minimum distance, the probability of undetected error in an asymmetric channel may be reduced by many orders of magnitude merely by the proper selection of coded characters. For a given minimum distance, an optimum selection of characters requires, as nearly as possible, the same number of "one" and "zero" bit failures to change one character to another. The concept of *polarized distance* is introduced, and it is shown how the probability of undetected error is related to the *minimum distance* of a code only in a symmetric channel, while the probability of undetected error is related to the *minimum polarized distance* in both symmetric and asymmetric channels.

The purpose of this paper is to present new theoretical concepts useful in the evaluation of codes, and not to recommend one code over another. The codes in the paper are used only as examples to illustrate the theoretical concepts involved.

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The Electronic Contribution to the Elastic Properties of Germanium *by R. W. Keyes, p. 266.* Theories of several elastic effects resulting from the contribution of electrons to the strain energy function of germanium are presented. They show that the elastic properties are appreciably changed by doping with donor and acceptor impurities. The properties considered are: (1) volume, (2) elastic constants of degenerate *n*-type material, (3) third-order elastic constants of degenerate *n*-type material, (4) elastic constants of degenerate *p*-type material, (5) elastic constants of material containing electrons bound to donors, (6) elastic constants of material containing electrons bound to pairs of donor atoms. The most striking effect is found for the case of degenerate *n*-type germanium, in which the theory predicts that c_{44} can be lowered by 8% with attainable doping levels.

Dislocations and Plastic Flow in Germanium *by D. Dew-Hughes, p. 279.* Single-crystal specimens of germanium have been tested in tension over a range of temperature and strain rate. Dislocation density has been determined as a function of plastic strain, and some direct measurements of dislocation velocity have been made. From these results the plastic behavior of germanium can be explained in terms of dislocation velocity and dislocation multiplication, and is analogous to the interpretation given by Johnson and Gilman for deformation of lithium fluoride. Effects of crystal purity and orientation have been examined; strain-aging effects were absent. Conjectures are made as to the causes of work hardening.

A High Track-Density Servo-Access System for Magnetic Recording Disk Storage *by A. S. Hoagland, p. 287.* This paper is concerned with an investigation of the feasible track-density potential of random-access magnetic-disk storage where magnetic-head positioning is essential. Primary emphasis is given to a novel, servo-access concept (closed-looped head-positioning control which includes the record member) for track location and registration. This servo concept has been investigated as a means of making possible automatic tracking as well as precision positioning. Inherent in such an access control technique is an enhanced suitability for interchangeable record members. Included in the discussion are design and performance results of an access model operated at 154 tracks per inch.

Lognormal Distribution Function for Describing Anelastic and Other Relaxation Processes I. Theory and Numerical Computations *by A. S. Nowick and B. S. Berry, p. 297.* Such phenomena as dielectric, magnetic, and anelastic relaxation are often described in terms of a distribution of relaxation times. It is shown that a relaxation process which exhibits a Gaussian distribution in the logarithm of the relaxation times

(a "lognormal" distribution) can be specified completely by three parameters. These are: the mean relaxation time (τ_m), the width of the distribution (β), and the magnitude of the relaxation (δJ). The relationships of these parameters to experimentally measurable functions are usually complicated. These relationships were obtained in numerical form by machine computation. Finally, a simple formula is derived which expresses the parameter β in terms of the widths of the distribution of the activation energies and that of the attempt frequencies.

Lognormal Distribution Function for Describing Anelastic and Other Relaxation Processes II. Data Analysis and Applications *by A. S. Nowick and B. S. Berry, p. 312.* The present paper deals with the use of the theory and computations given in Part I for a relaxation process governed by a lognormal distribution of relaxation times. The experimental determination of the basic parameters appearing in the theory is shown to require the application of a number of corrections to the usual type of dynamical data. General expressions are derived for these corrections, and the data necessary for their use are presented in graphical form. Specific examples are given of the application of the theory to the analysis of anelastic relaxation phenomena.

A Study of the Playback Process of a Magnetic Ring Head *by G. J. Y. Fan, p. 321.* The playback process of a magnetic ring head with finite permeability of head and tape are studied, using the theorem of reciprocity. In order to obtain an accurate result for the playback process, the field around a magnetic gap is studied by a Fourier method. The shift of the gap null for infinite permeability of the head as calculated by Westmijze is confirmed, and the new shift is found when the tape permeability is greater than one. A simplified gap-loss function is given for the case of finite parameters for tape and head.

A Note on Hall Probe Resolution *by H. Koehler, B. Kostyshyn, and T.-C. Ku, p. 326.*

The Chargistor, a New Class of Semiconductor Devices *by H.-N. Yu, p. 328.*

Monte Carlo Analysis of Transistor Diffusion Techniques *by D. P. Kennedy, p. 331.*

A Network Minimization Problem *by F. P. Palermo, p. 335.*

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Foreword: Fundamental Research in Superconductivity *by P. M. Marcus, p. 2.*

Review of the Present Status of the Theory of Superconductivity *by J. Bardeen, p. 3.* Theory and experiment are compared for a number of phenomena in superconductors. While the agreement is generally good, there are some discrepancies for which there is no adequate explanation.

On the Influence of Free Path on the Meissner Effect *by K. U. von Hagenow and H. Koppe, p. 12.* The influence of impurities on the behaviour of a superconductor is computed by introducing a scattering potential and averaging over all positions of the scattering centers. This procedure only takes into account scattering and free path effects and neglects changes in the elastic constants and electron density due to actual impurities. Using perturbation theory, it is shown that the free energy and the static Meissner effect are not influenced by scattering.

Solutions of the BCS Integral Equation and Deviations from the Law of Corresponding States *by J. C. Swihart, p. 14.* The BCS integral equation has been studied for nonseparable interactions of the Bardeen-Pines form, $V(|\varepsilon\varepsilon'|)$. Numerical solutions were obtained using an IBM 7090 for a simple interaction of this form which included the effect of the Coulomb repulsion. The results for the ratio of the energy gap to the critical temperature and for the temperature dependence of the energy gap, the electronic specific heat, and the critical field in terms of the proper reduced quantities were rather insensitive to the form or strength of the interaction. This indicates that the BCS theory gives the law of corresponding states. The calculated ratio of energy gap to critical temperature varies with the ratio of critical temperature to the Debye temperature, and this variation is of the correct order of magnitude if the Coulomb interaction is included. The same model is used to study the isotope effect. With the plausible assumption that the Coulomb cutoff is independent of the ionic mass, there are deviations from the $M^{-1/2}$ law that are larger for small T_c/θ_D superconductors.

Nuclear Spin Relaxation in Superconducting Cadmium *by Y. Masuda, p. 24.* The nuclear spin-lattice relaxation time, T_1, in superconducting cadmium has been measured in the range of 0.37K to 0.6K. A field-cycling method was used. The results are explained by the theory of Bardeen, Cooper, and Schrieffer, and give another confirmation of the theory. The temperature dependence of T_1 in cadmium is identical to that in aluminum, which is surprising in view of the different crystal symmetry and band structure of the two metals.

Experimental Work on Superconductivity *by K. Mendelssohn, p. 27.* The high thermal conductivity in the superconductive state at low reduced critical temperatures has been used for the detection of metal imperfections, including those caused by radiation damage. A statistically disordered single crystal of Ta with 30% Nb has also been investigated. Work is described on specific heats, ultrasonic attenuation and on the behaviour of thin superconductive films. An experiment for observing quantization of persistent currents is described.

The Kapitza Resistance of Metals in the Normal and Superconducting States *by W. A. Little, p. 31.* A calculation has been made of the transfer of heat across a metal-liquid helium interface. In the normal state an appreciable transfer of energy occurs directly from the conduction electrons to the phonons of the fluid. Three mechanisms have been considered: the phonon-electron interaction within the metal, the modulation of the position of the interface and the phonon-electron interaction of the electrons which have tunnelled into the helium. All appear to be important. In the superconducting state each of these becomes ineffective at temperatures appreciably below the transition temperature and, consequently, the heat flow is reduced. The effect is sensitive to band structure and to the anisotropy of the energy gap.

Superconductivity and Electron Tunneling *by S. Shapiro, P. H. Smith, J. Nicol, J. L. Miles, and P. F. Strong, p. 34.* Experiments on the tunneling of electrons through a thin dielectric layer separating two superconducting metals are reported. Data are presented for the pairs Al-Pb, Sn-Pb, and In-Sn. Particular attention is paid to the form of the tunneling current vs voltage characteristics and to the changes observed as a function of temperature. Experimental details relative to the measurement techniques, the preparation of the samples, and the preparation of the dielectric layers are presented. An analysis of the problem is presented which is based on the simple, one-dimensional model of the electron energy spectrum of a superconductor given by the theory of Bardeen, Cooper, and Schrieffer. Close quantitative agreement is obtained between the results of the calculations and the observed characteristics.

Magnetic Field Dependence of the Superconducting Energy Gap in Ginzburg-Landau Theory with Application to Al *by D. H. Douglass, Jr., p. 44.* A theoretical calculation is given of the magnetic field dependence of the superconducting energy gap, using the Ginzburg-Landau theory. In addition to depending upon the size of the specimen, the field dependence of the energy gap depends quite strongly on the nature of the boundary conditions. For the usual case with the magnetic field equal on opposite sides of a film, the calculations show that for a ratio of thickness, d, to penetration depth, λ, less than $\sqrt{5}$, the energy gap goes smoothly to zero as the critical field is approached—a second-order phase transition. When $d/\lambda > \sqrt{5}$, the energy gap approaches a finite value as the critical field is approached—a first-order phase transition. Energy-gap

measurements for aluminum agree very well with these calculations. When one changes the boundary conditions so that the magnetic field is constrained to be zero on one side of the film, the theory predicts a very different behavior. For this case, at all thicknesses, the energy gap approaches a finite value as the critical field is approached—a first-order phase transition. An experiment involving cylindrical films is proposed to test this latter case. It is shown that in this proposed experiment these boundary conditions are appropriate for predicting the *current* dependence of the energy gap.

Dependence of the Energy Gap in Superconductors on Position and Magnetic Field *by M. Tinkham, p. 49.* A review is given of work concerning the decrease of the energy gap in superconductors when a magnetic field is applied. The absence of any observable effect in previous spectroscopic work is explained, and conditions for large effects are outlined. Experimental measurements on thermal conductivity and microwave absorption in films in a magnetic field are described. The results show that in thin films, the gap can be depressed continuously to zero, yielding a second-order phase transition. In thicker films, the gap can be only partially depressed before the transition, and the transition is of first order. These results agree with those obtained theoretically by Douglass from the Ginzburg-Landau-Gor'kov theory, and experimentally, by electron tunnelling. An attempt to generalize the Ginzburg-Landau-Gor'kov theory to cope with the case when $\varepsilon_0/kT \neg 1$ is then indicated. In this phenomenological theory, the normalized gap $\varepsilon(H)/\varepsilon(0)$ is taken as an order parameter ω, and the free energy is assumed to contain a term in $\xi_0^2|\nabla\omega|^2$, as well as a free energy density $f(\omega)$ and magnetic energy $\kappa(\omega)H^2$. Some success is found.

Far-Infrared Absorption in a Lead-Thallium Superconducting Alloy *by D. M. Ginsberg and J. D. Leslie, p. 55.* Preliminary measurements have been made of the absorption of far-infrared radiation in the surface of a bulk superconducting alloy composed of lead with 10.0 atomic percent thallium at 1.4K. The results indicate that the gap edge is quite distinct, in contrast to previous results of Richards and Tinkham on other alloys. The sharpness of the gap edge is thought to be characteristic of alloys which are homogeneous and have no trapped magnetic flux. Alloying narrows the observed gap width by about the same ratio as the critical temperature, and by an amount which is much smaller than that predicted by Suhl and Matthias from a simplified model. The subsidiary absorption maximum below the gap edge, which has been seen previously in pure lead, is also present in the alloy. This lends support to other evidence that it is not due to crystalline anisotropy.

Ultrasonic Attenuation in Superconductors *by R. W. Morse, p. 58.* A brief review is given of the ultrasonic attenuation in metals arising from direct interaction of the elastic waves and conduction electrons, and the physical variables on which it depends. The drop in attenuation of longitudinal waves on entering the superconducting state is in good agreement with BCS theory, the various factors combining to make the relative attenuation, α_s/α_n, depend only on the energy gap; the measurements give evidence, however, for gap anisotropy or the presence of more than one gap. Recent measurements at Brown by Claiborne of shear wave attenuation in single-crystal Al, are in good agreement with a theory based on the Boltzmann and London equations. The steep drop at T_c is produced by shorting out of electromagnetic waves by supercurrents; the residual attenuation results from the effects of collision drag.

The Magnetic Behavior of Superconductors of Negative Surface Energy *by B. B. Goodman, p. 63.* Abrikosov and the author have separately suggested that a new type of reversible magnetic behavior is to be expected in superconductors whose coherence length is small compared with their penetration depth. The treatments of these two authors are shown to lead to similar results for pure metals and to only slightly different results for alloys. The experimental evidence in favor of a new type of reversible magnetic behavior in superconductors is discussed.

Effects of Electron Concentration and Mean Free Path on the Superconducting Behavior of Alloys *by B. R. Coles, p. 68.* A brief review is given of the superconducting behaviour of solid-solution alloys. Intermetallic compounds are not considered but some reference is made to secondary solid solutions. Two topics are discussed: some factors affecting the transition temperature, and the role played by surface energy between normal and superconducting regions.

Surface Energy Effects at the Boundary between a Superconductor and a Normal Conductor *by H. Meissner, p. 71.* Films of tin ranging from 500 to 1400 Å in thickness have been prepared in pairs by vacuum deposition onto rotating cylindrical glass and metal substrates. The temperature dependence of the critical fields has been measured. The critical temperatures of the films on metal substrates are all depressed. Their critical fields at absolute zero, however, are usually not depressed but can be higher than those of the corresponding films on glass. This increase can be explained by a negative surface energy arising from a short mean free path of the superconducting electrons in an incidental oxide layer at the surface of the metal. Most of the films on glass had an abnormally small value of the critical field at absolute zero.

Some Elementary Theoretical Considerations Concerning Superconductivity of Superimposed Metallic Films *by L. N. Cooper, p. 75.* A microscopic theory of superconductivity of superimposed metallic films is proposed, based on the fact that the electron pair correlation function penetrates into a normal metal where the electron-electron interaction would not by itself produce a superconducting state.

Thermodynamic Consistency of Magnetic and Calorimetric Measurements on Superconductors *by D. E. Mapother, p. 77.* Comparison of the entropy and specific heats of normal and superconducting tin and indium as computed from critical field and calorimetric measurements shows excellent consistency. Salient features of the comparison are briefly summarized. Some implications of the recently reported specific heat anomaly for indium are discussed.

The Temperature and Pressure Dependence of Critical Field Curves *by C. A. Swenson, p. 82.* A brief discussion is given of the analysis of recent critical field measurements. In particular, a negative volume coefficient of thermal expansion is predicted for tin in the superconducting state.

Mechanical Effects at the Superconducting Transition *by K. Andres, J. L. Olsen, and H. Rohrer, p. 84.* Work in Zürich on the difference in size and in expansion coefficient between the normal and the superconducting states is summarized. The volume dependences of the critical temperature and of the electronic density of states at the Fermi surface are discussed.

Variation of the Elastic Moduli at the Superconducting Transition *by G. A. Alers and D. L. Waldorf, p. 89.* Using an ultrasonic technique capable of measuring changes in the elastic moduli as small as one part in 10^7, the small modulus changes associated with the normal-to-superconducting transition have been measured as a function of both temperature and magnetic field. Single-crystal specimens of the cubic metals Pb, V, Nb and Ta were used and all their elastic moduli measured so that changes in the bulk modulus and Debye θ could be computed. The results showed that changes in the zero-point energy of the lattice can be far from negligible. Furthermore, the shear moduli are the most changed by the appearance of superconductivity.

First- and Second-Order Stress Effects on the Superconducting Transitions of Tantalum and Tin *by D. P. Seraphim and P. M. Marcus, p. 94.* The shift of critical field of a single-crystal wire under uniaxial tension is studied for Ta and Sn. For Ta the shift is nonlinear and gives both the first-order critical field-stress coefficient and a particular combination of second-order coefficients. By combining with other data, the three second-order constants are estimated. The smaller first-order coefficient of Sn is found to be considerably smaller than previous estimates. Both Ta and Sn are found to satisfy a similarity condition for the coefficients, but of a less restrictive form than usual. Similarity is used to predict the behavior of jumps in elastic constant moduli at the transition in Ta. The general formal theory of the first-and second-order coefficients is formulated and many special cases are given. The general thermodynamic relations at the transition between jumps in strain and elastic constants and the various coefficients, are derived. It is shown that BCS theory implies similarity.

Thermal Conductivity of Dilute Indium-Mercury Superconducting Alloys *by G. K. Chang, R. E. Jones, and A. M. Toxen, p. 112.* Thermal conductivities were measured for a series of polycrystalline alloys of indium containing 0.1 to 2.5 At.% mercury. Using theoretical models which relate the electronic thermal conductivity of a superconductor to its energy gap, the temperature and composition dependences of the energy gap have been calculated for these specimens. Estimates of the lattice thermal conduction were also obtained.

The Superconductivity of Some Intermetallic Compounds *by R. D. Blaugher, A. Taylor, and J. K. Hulm, p. 116.* The W-Os, Re-W, Re-Mo, Re-Hf, and Mo-Hf binary systems were investigated for superconductivity down to 1K. Several new superconducting regions were found with the most significant occurring in the primary and terminal solid-solution alloys. The occurrence of superconductivity in the β-phase field of the Re-Hf and Mo-Hf binaries indicates a possible explanation for the spurious superconducting effects sometimes observed in elemental hafnium.

High-Field Superconductivity in Some bcc Ti-Mo and Nb-Zr Alloys *by R. R. Hake, T. G. Berlincourt, and D. H. Leslie, p. 119.* Zero electrical resistance at unusually high magnetic field strengths has been observed in the bcc alloys Ti-16 a/o (atomic percent) Mo, Nb-12 a/o Zr, and Nb-25 a/o Zr. The maximum high-field zero-resistance current density, J_c, in these alloys appears to be a sensitive function of temperature, the degree of cold-working, and the orientation of the applied *transverse* magnetic field. For cold-rolled alloy specimens in an applied transverse field, J_c is a maximum or minimum, according to whether the field is set respectively parallel or perpendicular to the rolled face of the specimen. In Ti-16 a/o Mo the zero-resistance condition is observed in fields at least a factor 35 greater than the bulk material critical field as inferred from calorimetric data.

Anomalous Resistive Transitions and New Phenomena in Hard Superconductors *by M. A. R. Le Blanc, p. 122.* The value of the critical current (I_c)-critical field (H_c) of cold-worked Nb, Mo-Re and Nb-Zr wires at constant temperature is not a single-valued function of the field and current direction. The previous history of a specimen during an experiment plays an important role and a measurement of the critical field-critical current value can influence the response of the specimen to subsequent measurements. Anomalous resistive transitions are observed when I_c vs H_c curves are determined by proceeding from low to high fields which may not occur in measurements proceeding from high to low fields. Further, it is possible to condition a specimen to enable it to reach maximum values of the critical field and critical current. This phenomenon is also encountered in the operation of superconducting solenoids. The polarity of the field and current during this treatment is found to be significant. The effects of the rate increase of the current, of rotating the specimen in a transverse field, and of current density and temperature have also been studied.

Associative Memory with Ordered Retrieval *by R. R. Seeber and A. B. Lindquist, p. 126.* A basic associative memory utilizing cryogenic circuitry is described and its functions are compared with those of previously published associative memory descriptions. The ordered-retrieval sorting algorithm is described, along with its implementation by means of a ternary interrogating counter. A sorting example is given. The sorting efficiency is discussed and an efficiency formula is given. The required additions to the basic memory are outlined. Finally, some of the basic cryotron circuits are illustrated and their operation described.

Dual Programs *by P. Huard, p. 137.*

Domain Wall Creeping in Thin Permalloy Films *by S. Middelhoek, p. 140.*

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Some New High-Speed Tunnel-Diode Logic Circuits *by M. S. Axelrod, A. S. Farber, and D. E. Rosenheim, p. 158.* Several high-speed tunnel-diode logic circuits are presented which perform majority-type logic or majority-type logic with inversion, and make use of a multiphase sinusoidal power supply to obtain signal directivity. Laboratory results are presented which show operation of these circuits at a 125 Mc/sec pulse repetition rate with 2 nsec delay per logical decision. The circuits have also been operated at 250 Mc/sec.

A comparison which is made between these circuits and some of the tunnel-diode logic circuits previously reported in the literature reveals certain system advantages of the new circuits. Preliminary results of both analog and digital computer analyses of the systems of nonlinear differential equations which describe these circuits are presented. These results have been in excellent agreement with those found in the laboratory. A full serial binary adder is described which produces a carry output in 2 nsec and the sum output in 4 nsec.

Characterization of Tunnel Diode Performance in Terms of Device Figure of Merit and Circuit Time Constant *by L. Esaki, p. 170.* Tunnel diode oscillation, flip-flop switching and Goto twin operation have been characterized on the basis of numerical integration of a nonlinear differential equation representing transient behavior in the simplified, lumped equivalent circuit. The results have provided some information for the maximum utility of a tunnel diode having a given figure of merit. A useful relationship is given for single diodes, in which switching time vs external-circuit time constant L/R is shown for various device figures of merit. Another relationship is given for twin diodes in plots of cut-off frequency vs L/R. The study is then extended to the case of oscillator diodes.

Systematics of the Evoked Somatosensory Cortical Potential *by W. R. Uttal and L. Cook, p. 179.* This paper presents the results of a series of experimental studies in which a digital computer averaging technique was used to explore the dynamics of the electric response of the human somatosensory cortex evoked by pulse electrical stimulation of nerves in the wrist.

A nomenclature is presented for the typical components of the complex waveform which the authors consider to be representative of the evoked potential. The effects of stimulus amplitude, bilateral and bitemporal stimulation, and sleep on the evoked corticogram were investigated. Psychophysical studies were also carried out which complemented the evoked potential studies, and comparisons were made between the neurological and psychological data.

Charge Transport Mechanisms in the Transfer of Latent Electrostatic Images to Dielectric Surfaces *by R. M. Schaffert, p. 192.* The transfer of electrostatic charge patterns from one surface to another requires movement of electrical charges across very small air gaps. Gaseous electronics alone is not sufficient to account for charge transport across extremely small gaps. The concept of field emission is introduced as a supplementary mechanism of charge transport and as a source of primary electrons.

The Use of Triple-Modular Redundancy to Improve Computer Reliability *by R. E. Lyons and W. Vanderkulk, p. 200.* One of the proposed techniques for meeting the severe reliability requirements inherent in certain future computer applications is described. This technique involves the use of triple-modular redundancy, which is essentially the use of the two-out-of-three voting concept at a low level. Effects of imperfect voting circuitry and of various interconnections of logical elements are assessed. A hypothetical triple-modular redundant computer is subjected to a Monte Carlo program on the IBM 704, which simulates component failures. Reliability is thereby determined and compared with reliability obtained by analytical calculations based on simplifying assumptions.

Pseudo Division and Pseudo Multiplication Processes *by J. E. Meggitt, p. 210.* Some digit-by-digit methods for the evaluation of the elementary functions are described. The methods involve processes that resemble repeated-addition multiplication and repeated-subtraction division. Consequently, the methods are easy to implement and the resultant execution times are short.

Minimization Over Boolean Graphs *by J. P. Roth and R. M. Karp, p. 227.* This paper presents a systematic procedure for the design of gate-type combinational switching circuits without directed loops. Each such circuit (Boolean graph) is in correspondence with a sequence of decompositions of the Boolean function which it realizes. A general approach to functional decomposition is given and, in terms of a convenient positional representation, efficient tests for the detection of decompositions are derived. These results are

employed in the development of an alphabetic search procedure for determining minimum-cost Boolean graphs which satisfy any given design specifications.

Generalizations of Horner's Rule for Polynomial Evaluation *by W. S. Dorn, p. 239.* Polynomials are generally evaluated by use of Horner's rule, sometimes referred to as the nesting rule. This rule is sequential and affords no opportunity for parallel computation, i.e., completion of several of the arithmetic operations simultaneously. Two generalizations of Horner's rule which allow for parallel computation are presented here.

Schedules and, in some cases, machine codes for evaluating a polynomial on a computer with several parallel arithmetic units are developed. Some advantages of the generalized rules in sequential computations on a computer with a single arithmetic unit are presented.

Approximate Methods for a Multiqueueing Problem *by G. Schay, Jr., p. 246.* Two approximate methods are described and used to obtain the stationary distribution of the length of a queue which is a small part of a system of many queues. The methods are based on an analogy to statistical mechanics, and give simple approximate solutions of a problem whose exact handling would be extremely complex and would require much more information than is available.

Superconductivity and Ferromagnetism *by B. T. Matthias, p. 250.* The close relationship between superconductivity and ferromagnetism is discussed and illustrated; it is suggested that several mechanisms cause superconductivity and also ferromagnetism. Various rare earth alloys show simultaneous superconductivity and dilute ferromagnetism. Such dilute ferromagnetism does not occur, however, in the transition-metal superconductors. Striking differences in the effects of adding magnetic elements to transition-metal superconductors are traced to the presence or absence of localized magnetic moments; such occurrences show a dependence on electron concentration similar to superconductivity. Superconductivity in the transition and nontransition elements shows a simple dependence on valence electron concentration—but when such elements are mixed they interfere drastically.

Isotope Effects in Low Temperature Superconductors *by T. H. Geballe and B. T. Matthias, p. 256.* The critical temperatures of different isotopes of osmium and of zinc have been measured. The results are that Os has no isotope effect, while with Zn the critical temperature is proportional to $M^{-\frac{1}{2}}$. These findings, together with our previous work on ruthenium, are consistent with the statement that there is no isotope effect for the transition elements, whereas the full $M^{-\frac{1}{2}}$ effect exists for nontransition elements.

On the Influence of Free Path on the Meissner Effect *by D. C. Mattis, p. 258.*

Comment on "A Network Minimization Problem" *by M. Tideman, p. 259.*

A Theoretical Solution for the Magnetic Field in the Vicinity of a Recording Head Air Gap *by E. E. Francis and T.-C. Ku, p. 260.*

Application of Differential Interferometry with Two Polarized Beams *by C. Le Méhauté, p. 263.*

Comments on the Presence Function of Gazalé *by T. Rado, p. 268.*

Concerning the Possibility of a Cooperative Information Exchange *by M. Kochen and E. Wong, p. 270.*

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Rectification of Satellite Photography by Digital Techniques *by R. E. Mach and T. L. Gardner, p. 290.* Sample photographs from the TIROS I Weather Satellite have been successfully transformed into a Mercator projection using automatic digital techniques. Mathematical formulas expressing the relation between the photoplane and the Mercator projection have been derived, and a computer program has been written to efficiently manipulate a "digital photograph" in accordance with the formulas.

Multiple Input-Output Links in Computer Systems *by B. B. Tasini and S. Winograd, p. 306.* An algorithm is developed for the analysis and design of computing systems having a multiplicity of concurrent and independent information sources and a lesser number of input channels to the processing elements of a digital computer; the input-output links work simultaneously with the processing and computing elements of the system. Utilizing this algorithm, such problems pertaining to the amount of hardware and the interconnection of its components can be resolved. For an optimum system design, its parameters are subject to two major criteria, i.e., the amount of information transmitted to the central processing elements per unit time, and the degree of overlapping of input output operations with computing (or other processing operations) that can be attained. Part I of this paper is devoted to information sources of the sequential access, serial-by-character (or-bit) transmission class. Magnetic tape units are specifically dealt with. With minor modifications the method is applicable to other information sources of the same class. In Part I, three fundamental system configurations are discussed and results of computations are summarized. In Part II, information sources of the quasi-random and random access class are investigated within the framework established in Part I. Disk files were selected as a specific representative of the quasi-random and random access information sources.

Diffusion of Gas from a Liquid into an Expanding Bubble *by E. J. Barlow and W. E. Langlois, p. 329.* The growth of a bubble within a volume of isothermal viscous liquid containing uniformly distributed dissolved gas is considered. The problem of characterizing this growth-by-mass-transfer is reduced to an integro-differential equation for the bubble radius as a function of time, and a computer solution is obtained. The initial and final stages of growth are treated analytically.

Spin Absorption Spectra *by L. S. Brown, p. 338.* Spin systems exhibit a whole spectrum of absorption lines when in small constant external magnetic fields giving Zeeman energies comparable to internal interaction energies. With such small constant magnetic fields, power is absorbed from an alternating magnetic field at zero frequency, at the Larmor frequency, and at harmonics of the Larmor frequency, both for perpendicular- and parallel-field configurations. The calculation of this spectrum for spin systems in powdered materials is the main purpose of this paper. Both magnetic dipole-dipole and electric quadrupole internal interactions are considered and treated as second-order perturbations on the Zeeman interaction. The intensities of the two absorption lines that occur at the Larmor frequency and double the Larmor frequency are obtained for the parallel-field case. The intensity, frequency shift, and second moment of the Larmor line, and the intensities of the lines that occur at zero frequency and double the Larmor frequency, are obtained for the perpendicular-field case. The second-order calculation for powdered materials gives results which are identical within a constant factor for both dipole-dipole and quadrupole interactions.

An Experiment on the Effect of Particle Orientation on Peak Shift in Magnetic Tapes *by G. Bate, H. S. Templeton, and J. W. Wenner, p. 348.* One of the limiting factors in high-density recording on magnetic tape is the phenomenon of peak shift. With the NRZI code (flux change on a ONE, no flux change on a ZERO) this means that the reproduced signals from two successive ONES preceded and followed by ZEROS are separated in time by more than the natural bit period. The peaks in the signal output from the two ONES are thus shifted outwards. An experiment is described in which the peak shift is measured in particle-oriented tape as a function of the angle θ between the direction of recording and the direction of orientation. The dc hysteresis properties of the tape were also measured as a function of θ. It was found that the peak shift had a minimum when θ was approximately 65° for the tape and recording head used in this experiment. At this angle the remanence-coercivity was high, while the coercivity and the ratio of remanence to saturation intensity were low. Qualitative explanations of these results are offered and their significance is briefly discussed.

A "Logical Pattern" Recognition Program *by R. E. Bonner, p. 353.* A description is given of an IBM 7090 program which searches for "logical patterns" in a set of input samples. The program was tested on a character recognition problem, where it designed a recognition system whose error rate and hardware requirements are compared to those of a system designed by humans. This program is intended to be used as a research tool to discover certain kinds of patterns in data and as a step in the direction of automatic logic design for some character recognition problems.

Optical Mixing of Coherent and Incoherent Light *by A. W. Smith and N. Braslau, p. 361.*

Fluorescence of Europium Tungstate *by R. E. MacDonald, M. J. Vogel, and J. W. Brookman, p. 363.*

A Note on the Nature of RNA Codes *by S. A. Bernhard and W. L. Duda, p. 365.*

Partial-Switching Processes in Thin Magnetic Films *by W. Dietrich, p. 368.*

Direct Observation of Dislocation Loops in Arsenic-Doped Germanium *by G. E. Brock and C. F. Aliotta, p. 372.*

Electron Beam Microanalysis of Germanium Tunnel Diodes *by M. I. Nathan and S. H. Moll, p. 375.*

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Static Reversal Processes in Thin Ni-Fe Films *by S. Middelhoek, p. 394.* Magnetization reversal at an angle to the easy direction in Ni-Fe films was studied. The results, in contrast to the single-domain theory, show no coherent rotation, even for field directions in which the critical field for rotation is smaller than the critical field for wall motion. The actual reversal is initiated by rotation of the magnetization in bands formed in the film. New experimental studies show that the reversal is subsequently completed by wall motion. A qualitative discussion of the new observations and a review of previous work give a comprehensive picture of the static reversal processes in thin Ni-Fe films.

A Discrete Queueing Problem with Variable Service Times *by P. E. Boudreau, J. S. Griffin, Jr., and M. Kac, p. 407.* Methods from the theory of Markov chains are used to analyze a simple single-server queueing model. The model is of the sort that arises naturally in information-handling contexts, in that a discrete time basis is used, which matches the cyclic character of processors. Considerable generality is attained, in that no appeal is made to the exponential or other conventional forms for the probability distributions governing the number of arrivals per cycle and the service times.

The principal object of study is the queue length; the stationary distribution governing this quantity is calculated, along with various associated averages. The relation between the present method and the more usual continuous-variable

method is illustrated by the derivation of some of the classical equations from a limiting case of our model.

Analysis of Static and Quasidynamic Behavior of Magnetostatically Coupled Thin Magnetic Films *by H. Chang, p. 419.* When two superposed films exert fields on each other, their static and dynamic behaviors change. The following method or analysis is used to study the behavior: The stable states are found by minimizing the total free energy of the films. Then constant-field contours are plotted in the θ_1-θ_2 plane (θ's being the stable orientations of the magnetization vectors). In examining the plot, one can predict multiple stable states, switching, threshold, hysteresis, and the detailed paths of magnetization change as a function of applied field.

The solution is carried out by a numerical process which permits evaluation of the following effects: the variation of the degrees of symmetries of the anisotropy energies, the relative orientation between the films, the coupling strength, and the drive-line layout. An example is carried out in sufficient detail for illustrative purposes.

Coding for Logical Operations *by S. Winograd, p. 430.* The behavior of a computation system consisting of encoders, an unreliable logical operator and a decoder is investigated. It is shown that for almost all Boolean functions, coding each block of k input bits into a block of n bits such that all sets of s or less errors will be corrected requires that $n \geq (2s + 1)k$. This result suggests that the capacity (in the information theoretical sense) of such a computation system is zero.

Experimental Study of Electron-Beam Driven Semiconductor Devices for Use in a Digital Memory *by J. W. Horton, p. 437.* A novel method of electronic storage is proposed, in which an electron beam would be used to drive active and passive semiconductor devices to perform the functions of a digital memory, including those of nondestructive read-out and reset. Principally to ascertain what speeds and output signals might be currently obtained if the storage method were implemented, an experimental study was made of the response to a bombarding electron beam of commercial "four-layer" and surface-barrier diodes which could function in the proposed store respectively as storage diodes and read-out diodes. Data presented on the Shockley Laboratories' silicon 4N20D "four-layer" diode give the reduction of firing voltage caused by the bombardment as a function of beam current and bombardment duration. It is found that a beam current as weak as 0.2 μamp can fire a diode in 1/5 μsec. Three types of germanium surface-barrier diodes were studied for maximum speed of response to the bombarding beam current pulse and for charge multiplication. The "fastest" unit tested was a Philco 2N502 transistor modified for beam access to the base region by removal of the emitter dot. This unit could be bombarded to produce a 50 nsec pulse of 0.4 v peak across a 1000-ohm load. In the light of these data and of circuit and semiconductor device theory, a preliminary discussion is presented of the feasibility of a store providing a read-in rate of 5 megapulses/sec, a read-out rate of 15 megapulses/sec and a read-out signal ratio of stored ONES to stored ZEROES of 50 to 1.

Residual Stress in Single-Crystal Nickel Films *by J. F. Freedman, p. 449.* Experiments are described which directly indicate the source, magnitude and direction of the residual stress on single-crystal nickel films evaporated on rock salt. A theoretical analysis using the five-constant magnetostriction equation shows how this stress affects the magnetic properties. X-ray diffraction studies indicate that the as-evaporated films exist in a highly strained condition, resulting in a tetragonal distortion of the cubic symmetry. The parameters of the unit cell are $a = b = 3.500 \pm 0.004$ Å in the plane of the film and $c = 3.546 \pm 0.002$ Å normal to the film. The stress causing this strain is elastic in character. When the film is floated off the rock salt, the parameter decreases to bulk unstrained Ni, $a_0 = 3.524$ Å.

The calculation using bulk elasticity data yields a planar compressive stress $\sigma = 1.0 \times 10^{10}$ dyne/cm^2, from differential thermal expansion between nickel film and NaCl substrate. This externally applied stress system influences the magnetic state of the film by contributing to the total energy of the system through a magnetoelastic interaction.

A Polarimetric Method of Measuring Magneto-Optic Coefficients *by H. B. Bebb, p. 456.* Formulas are established which allow polarimetric determination of the amplitudes and relative phases of the Kerr (and Faraday) coefficients for ferromagnetic metals. The results are valid only for oblique angles of incidence. Hence, the technique is most useful for measurement of thin films where the magnetization vector lies in the plane of the film.

Printed Cards for the Card Capacitor Memory *by J. W. Haskell, p. 462.*

Determination of Lattice Strain and Crystallite Size in Thin Films *by A. Segmüller, p. 464.*

Direct Observations of the Substructure Network in Iron *by W. L. Mitchell, C. Hays, and R. E. Swift, p. 467.*

A Note on Some Fundamental Parameters of Multiqueue Systems *by M. A. Leibowitz, p. 470.*

Effect of Initial Air Content on the Dynamics of Bubbles in Liquids *by J. T. S. Ma and P. K. C. Wang, p. 472.*

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Computer-Automated Design of Multifont Print Recognition Logic *by L. A. Kamentsky and C.-N. Liu, p. 2.* A computer program has been written to design character recognition logic based on the processing of data samples. This program consists of two subroutines: (1) to search for logic circuits having certain constraints on hardware design, and (2) to evaluate these logics in terms of their discriminating ability over samples of the character set they are expected to recognize. An executive routine is used to apply these subroutines to select a complete logic with a given performance and complexity. This logic consists of 39 to 96 AND gates connected to a shift register and a table look-up or resistance network comparison system.

The methods were applied to the design of recognition logics for the 52 upper and lower case characters of IBM Electric Modern Pica type font and lower case Cyrillic characters scanned from Russian text. In both cases when the logics were tested on data different from that used to design the logics, the substitution rate was about one error per thousand. A single logic was designed to read two different Cyrillic fonts. For this design, an error rate of one error per hundred characters was observed.

Several experiments are reported on a number of logics designed for typewritten data, and single- and two-font Cyrillic data. The performances of different recognition systems are compared as a function of the complexity of the recognition logics.

The Recognition of Handwritten Numerals by Contour Analysis *by E. C. Greanias, P. F. Meagher, R. J. Norman, and P. Essinger, p. 14.* A character recognition system has been developed for the recognition of handwritten numerals. This system uses a logically controlled cathode ray tube scanner to generate basic measurements that characterize significant features of the numeral shapes. A contour-follower procedure is used to control the scanner. In addition, special scanner subroutines initiated by feedback from the recognition logic are utilized. Character shape data are generated in a sequential form, which can be analyzed for recognition with an easily realizable logic.

An experimental model has been built that recognized 99.3% of numerals written by 45 subjects after 30 minutes of training. The error rate for these characters was 0.11%. The rejected character rate was 0.59%.

Increased Magnetic Recording Read-back Resolution by Means of a Linear Passive Network *by H. M. Sierra, p. 22.* It has been proven that the principle of superposition applies to a magnetic read-back waveform. Consequently, each pulse can be treated as an isolated transient, and a linear passive network can be used to reduce its width. In many cases this effective increase in read-back resolution would permit an increase in the operating density. The isolated read-back pulse is first approximated by a Gaussian curve. A second approximation is effected in the frequency domain, and a table of transfer functions is obtained. A network is designed using one of the transfer functions, and the solution is given an algebraic form. One particular case is illustrated numerically and the laboratory results are shown.

Anomalous Photoelectric Emission from Nickel *by I. Ames and R. L. Christensen, p. 34.* The photoelectric emission from a nickel ribbon has been observed as a function of temperature from 25° to 760°C, over a wavelength range from 2250 to 2530 Å, qualitatively confirming and extending Cardwell's earlier work. The yield increases with temperature at all wavelengths, with an upward bulge near the Curie point. Fowler-Dubridge analyses of the emission from the front face of the ribbon, which is found to contain mainly (111) facets after extensive outgassing, yield values of the work function ranging from about 5.07 ev at 25°C to about 5.20 ev at 760°C. Behavior below the Curie point may be consistent with the magnetization-squared dependence recently suggested by Wonssowski, et al.

Synthesis of Transfer Admittance Functions Using Active Components *by F. J. Hudson, p. 40.* A formal synthesis procedure is developed for active networks. The transfer admittance function is realized in parallel *RC* subnetworks, one of which contains a current-reversal negative impedance converter. This procedure offers several advantages over existing methods.

Investigations of the Electro-Optical Birefringence of Polydisperse Bentonite Suspensions *by M. J. Shah and C. M. Hart, p. 44.* Colloidal suspensions of bentonite were observed to undergo a negative electro-optical birefringence at low-voltage fields even in dilute suspensions, a phenomenon not reported earlier. Experimental results do not support a previous theory that the sign of birefringence is reversed because of various particle sizes. Although interaction between particles was found to augment this low-voltage anomalous behavior, we believe that in dilute solutions this behavior is caused by some inherent property of the bentonite micelle. This contention is supported by variation in the relaxation times in negative and positive birefringence regions, thus suggesting orientation on two different axes in the two respective regions.

Threshold Relations and Diffraction Loss for Injection Lasers *by G. J. Lasher, p. 58.* Mathematical expressions are derived for the minimum current density necessary to cause stimulated emission in injection lasers. A new type of diffraction loss for a thin light-emitting layer surrounded by light-absorbing material is calculated.

Directionality Effects of GaAs Light-Emitting Diodes: Part I *by G. Burns, R. A. Laff, S. E. Blum, F. H. Dill, Jr., and M. I. Nathan, p. 62.*

Directionality Effects of GaAs Light-Emitting Diodes: Part II *by R. A. Laff, W. P. Dumke, F. H. Dill, Jr., and G. Burns, p. 63.*

Electromagnetic Mode Population in Light-Emitting Junctions *by W. P. Dumke, p. 66.*

Paramagnetic Resonance of the Shallow Acceptors Zn and Cd in GaAs *by R. S. Title, p. 68.*

Determination of the Active Region in Light-Emitting GaAs Diodes *by A. E. Michel, E. J. Walker, and M. I. Nathan, p. 70.*

Room-Temperature Stimulated Emission *by G. Burns and M. I. Nathan, p. 72.*

CW Operation of a GaAs Injection Laser *by W. E. Howard, F. F. Fang, F. H. Dill, Jr., and M. I. Nathan, p. 74.*

Experimental Study of Human Factors for a Handwritten Numeral Reader *by M. N. Crook and D. S. Kellogg, p. 76.*

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Some New Classes of Cyclic Codes Used for Burst-Error Correction *by E. Gorog, p. 102.* A general theory of cyclic codes correcting a set of given types of errors is presented. Codes published by Abramson, Fire, Melas and others are accounted for in this theory, which also offers several new classes of codes. These new codes are competitive with existing ones. In burst-error correction, for certain message lengths they may be better since they may need fewer parity check bits.

The Lightly Loaded Foil Bearing at Zero Angle of Wrap *by W. E. Langlois, p. 112.* A method is developed for determining, to the first order, the deflection from a straight path of a perfectly flexible tape moving near a rigid cylinder. The case of a parabolic cylinder is considered.

Propagation of Torsional Disturbances in a Homogeneous Elastic Sphere *by Y. Satô, p. 117.* Localized torsional stress is applied on the surface of a homogeneous elastic sphere for a short duration of time. The propagation of the disturbance caused by this stress is calculated numerically by superposing the normal mode solutions. The phases of the body waves and surface waves are obtained.

A Method for Key-to-Address Transformation *by G. Schay and N. Raver, p. 121.* Techniques used in the theory of error-correcting codes are applied to solve the problem of addressing a large file. This novel approach to the file addressing problem is illustrated with a specific design to show feasibility. Its effectiveness is further illustrated by comparing test results obtained from a simulated calculation, which used typical data, against values calculated from an ideal model.

An Application of Coding Theory to a File Address Problem *by M. Hanan and F. P. Palermo, p. 127.* In this paper a file address problem is proved to be equivalent to a problem in coding theory. Results in coding theory can thus be used in solving this file addressing problem. It is shown, in particular, how the theory of Bose-Chaudhuri codes can be applied. A simple transformation from the input information to its address is given. This method can be easily implemented using either a computer or shift registers.

Magnetization of Uniaxial Cylindrical Thin Films *by H. J. Kump and T. G. Greene, p. 130.* An analysis is given of the magnetization of a cylindrical thin film exhibiting a uniaxial anisotropy in the circumferential direction. The magnetization and demagnetizing fields are derived for the cylinder where the magnetization is not uniform. The derivation is accomplished by dividing up the cylinder into a large number of uniformly magnetized, coaxial cylindrical regions in superposition and by integrating their individual contributions. Some applications of the derivation are shown for several specified field geometries. The technique of superposition may be applied to other film geometries.

A Liquid Scintillation Counter Using Anticoincidence Shielding *by G. J. Sprokel, p. 135.* A liquid scintillation counter with an active volume of one liter is described. The plastic anticoincidence shield reduces background by about 25 percent in the H^3 and C^{14} region. Photomultiplier noise is effectively eliminated by nanosecond coincidence circuitry. The tunnel diodes used in the coincidence arrangement also act as baseline or window discriminators. Counting efficiency for C^{14} solutions is 85 percent, limited mainly by light collection.

Fly's-Eye Lens Technique for Generating Semiconductor Device Fabrication Masks *by W. E. Rudge, W. E. Harding, and W. E. Mutter, p. 146.*

A Note on Extending Certain Codes to Correct Error Bursts in Longer Messages *by C. M. Melas and E. Gorog, p. 151.*

Nominal Clearance of the Foil Bearing *by H. K. Baumeister, p. 153.*

Line Widths and Pressure Shifts in Mode Structure of Stimulated Emission from GaAs Junctions *by M. J. Stevenson, J. D. Axe, and J. R. Lankard, p. 155.*

Threshold Current for *p-n* Junction Lasers *by J. L. Moll and J. F. Gibbons, p. 157.*

On the Direct Observation of the Substructure Network in Iron *by G. Koves and J. Pesch, p. 160.*

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A Circuit Packaging Model for High-Speed Computer Technology *by F. K. Buelow, F. B. Hartman, E. L. Willette, and J. J. Zasio, p. 182.* An exploratory model has been constructed in a study of packaging and circuit techniques for a high-speed computer technology. An Arithmetic and Logic Unit capable of processing 64-bit words in floating-point format was fully designed. From this design a nucleus system comprising 424 circuits and 1838 transistors was abstracted, built, and tested. In this model, a delay of 2.2 nsec per level of logic was achieved in worst-case paths. This figure includes the wiring and power driver delays.

Design of ACP Resistor-Coupled Switching Circuits *by D. H. Chung and J. A. Palmieri, p. 190.* Directly coupled logic circuits utilizing silicon transistors have been developed in the Advanced Circuit Program. Silicon transistors possess sufficient field gradient in the collector-base "diode" to permit high-speed operation under a forward-biased condition. Current-switching techniques provide the well-controlled voltage levels which permit operation in this region without sacrificing high speed. Operation in this region permits circuit simplification and low power dissipation.

A desirable state-of-the-art device is defined. Design techniques which result in a compatible set of logic circuits and power amplifiers are described. Germanium tunnel diodes are used in power driving and transmission line driving circuits.

In order to measure the delay times, a model with 424 circuits was subsequently built. ACP circuits (the name adopted for this circuit family) were found to perform two levels of logic in 3.2 nsec.

An Improved Tunnel Diode Memory System *by D. J. Crawford, W. D. Pricer, and J. J. Zasio, p. 199.* Beginning with a brief history of tunnel diode memories, this paper describes the factors leading to the present design approach. Array design criteria are discussed at length. Examples of engineering applications are given, including a cross-sectional model of a "scratch pad" memory for use with Advanced Circuit Program logic circuitry.

Transient Analysis and Device Characterization of ACP Circuits *by K. G. Ashar, H. N. Ghosh, A. W. Aldridge, and L. J. Patterson, p. 207.* Characterization of devices for high speed ACP (Advanced Circuit Program) circuits demands an accurate study of transients and switching delays. This paper describes (a) the large-signal transistor model evolved for the purpose of carrying out such an analysis; (b) methods of measuring device parameters with relevant theory; (c) computational techniques most adaptable; and (d) correlation between predicted and observed transients. Many new ideas in the development of the device model, measurements, and computational procedure are reported and could be used for any general circuit analysis.

A New Model for Error Clustering in Telephone Circuits *by J. M. Berger and B. Mandelbrot, p. 224.* This paper proposes a new mathematical model to describe the distribution of the occurrence of errors in data transmission on telephone lines. We suggest: a) that the statistics of telephone errors can be described in terms of an error probability depending solely on the time elapsed since the last occurrence of an error; b) that the distribution of inter-error intervals can be well approximated by a law of Pareto of exponent less than one; the relative number of errors and the equivocation tend, therefore, to zero as the length of the message is increased. The validity of those concepts is demonstrated with the aid of experimental data obtained from the German telephone network. Further consequences, refinements, and uses of the model are described in the body of the paper.

Digit-by-Digit Methods for Polynomials *by J. E. Meggitt, p. 237.* This paper presents a general system configuration for an arithmetic unit of a computer, which is used to solve polynomial problems efficiently. The technique is based on a digit-by-digit computation of the coefficients of the given polynomial, after the origin has been displaced systematically. Compared with standard techniques, the new scheme, closely allied with Horner's method, is similar in efficiency for polynomial evaluation and is superior for locating roots. The fact that the computed coefficients are related to the derivatives permits the systematic location of all real roots of a real polynomial.

Automatic Determination of Amino Acid Sequences *by S. A. Bernhard, D. F. Bradley, and W. L. Duda, p. 246.* A fundamental problem for biochemistry is the determination of the linear sequence of amino acids in proteins. This paper describes a computer-oriented logic for obtaining such determination. The logic applies successively stronger decision rules to extract the required information on the protein sequence.

Directional Coupling and its Use for Memory Noise Reduction *by G. F. Bland, p. 252.*

A Simple Active Equivalent to a Lattice Pulse-Slimming Filter *by P. D. Dodd, p. 257.*

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Nonlinear Wave Propagation in a Transmission Line Loaded with Thin Permalloy Films *by M. C. Gutzwiller and W. L. Miranker, p. 278.* This paper considers the propagation of waves in a transmission line loaded with thin permalloy films. Since the films are driven to saturation, the transmission line equations which are derived to describe the

wave propagation are nonlinear. The nonlinearity requires the use of shock wave analyses, and a derivation of the appropriate shock relations is included. The problems of a line loaded with a single film and a line loaded with a periodic array of films are both treated. The saturation front moving along a string of films is shown to be the shock front. The shock speed, which is determined in terms of the parameters of the circuit, is then the operational speed limit of a thin film memory.

A Theoretical Model for Separation in the Fluid Jet Amplifier *by Y.-O. Tu and H. Cohen, p. 288.* A theoretical study, based on the re-entrant jet model, is made of the growth of the separation region in the fluid jet amplifier. The flow is taken to be inviscid but dissipation of momentum is obtained by means of the re-entrant jet. The effect of control port pressure and wall angle on the size of the separation region is calculated. Several other versions of the model are suggested.

Prenucleation of Lead Films with Copper, Gold, and Silver *by R. H. Jeppesen and H. L. Caswell, p. 297.* Lead films evaporated onto thin nucleating layers of Cu, Ag, and Au were studied by the techniques of electron diffraction and electron microscopy. Electron micrographs indicated that films nucleated with Au become continuous much sooner than films nucleated with Ag or Cu. Examination of the diffraction pattern showed Au to be the only metal of the three to form an intermetallic compound with lead, indicating that compound formation aids in nucleation.

Analysis and Numerical Calculations of the Dynamic Behavior of Plane Pivoted Slider Bearings *by W. Stuiver and R. S. McDuffie, p. 303.* The dynamic behavior of plane, self-acting, pivoted slider bearings of infinite length is examined for the case of an incompressible lubricating film. The equations of motion for the slider are derived, with the lubricant force expressed in terms of the motion-coordinates and their derivatives and of the parameters that characterize the system. Equilibrium positions of the system are determined numerically and the stability of small motions in the neighborhood of these positions is examined. The nature of large motions is investigated by numerical integration of the equations of motion, and the transient behavior of the system is shown and discussed for some specific cases.

Automatic Correction of Multiple Errors Originating in a Computer Memory *by P. R. Daher, p. 317.* An error correction unit has been installed in an IBM RAMAC® 305 to demonstrate automatic correction of burst errors originating in a computer memory. Employing a cyclic code requiring two percent redundancy, the unit has successfully corrected all four-bit and most five-bit error bursts in a 100-character record stored on a defective disk. Details of the error correction unit and test results are presented; two special cases involving block length are also discussed.

A Data Display Subsystem *by J. E. Dammann, E. J. Skiko, and E. V. Weber, p. 325.* A cathode ray tube device is described in which up to 4000 flicker-free characters are displayed dynamically. The developmental system is designed to permit monitoring the display while data are inserted, deleted or corrected by means of a keyboard. This system uses a novel positioning method which combines electrostatic and magnetic techniques.

Nonlinear Absorbers of Light *by R. W. Keyes, p. 334.*

Tagging Techniques for Incorporating Microglossaries in an Automatic Dictionary *by G. O. Tarnawsky, p. 337.*

Automatic Step-Size Control for Runge-Kutta Integration *by R. M. Warten, p. 340.*

High-Speed Photographs of Laser-Induced Heating *by T. J. Harris, p. 342.*

Diffraction by a Finite Sinusoidal Phase Grating *by E. S. Barrekette and H. Freitag, p. 345.*

On a Queueing Problem Arising in Recirculating Memories *by G. Schay, Jr., p. 350.*

Further Results in Polynomial Addressing *by C. V. Freiman and R. T. Chien, p. 353.*

An Amendment to "A Theoretical Solution for the Magnetic Field in the Vicinity of a Recording Head Air Gap" *by T.-C. Ku, p. 355.*

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Speech Synthesis from Stored Data *by S. E. Estes, H. R. Kerby, H. D. Maxey, and R. M. Walker, p. 2.* The synthesis of speech by joining together segments derived from natural speech has not proven to be satisfactory with segments smaller than words, especially because of discontinuities in pitch and formant frequencies at the junctions. It appears that segmentation of the control signals for an analog synthesizer may avoid these difficulties. This paper describes an experimental system to investigate this method. A library of synthesizer control signals corresponding to subword segments of speech is now being developed. The equipment used to generate the library of control signals, as well as that used to synthesize connected speech from the library, is described.

The synthesizer is a transistorized terminal analog of the cascade type. The synthesizer control signals are originally derived from functions drawn on a transparent plastic belt with opaque tape and scanned by a CRT and photomultiplier. The control signal functions are varied until the speech segment being studied is satisfactory. The resulting control signals corresponding to the speech segment are then automatically digitized and recorded on punched cards for addition to the library. Connected speech may be generated by computer assembly of the synthesizer control signals corresponding to a sequence of speech segments. In the assembly of connected speech from the library segments, pitch and timing may be specified independently of the sequence of segments if desired.

Attenuation of a Magnetic Field by a Superconductor *by K. E. Drangeid, R. Sommerhalder, H. Müller, and H. Seitz, p. 13.* Observation of magnetic ac field penetration through superconducting tin films has led to the discovery of a 180° phase shift between the magnetic fields on either side of the film under favorable conditions. This result has so far been published only in a short note, and the present paper presents a detailed description of the experimental technique. A more quantitative discussion, with emphasis on the physical aspects of field attenuation in superconductors, will be published in a future paper.

On Some Clustering Techniques *by R. E. Bonner, p. 22.* The problem of organizing a large mass of data occurs frequently in research. Normally, some process of generalization is used to compress the data so that it can be analyzed more easily. A primitive step in this process is the "clustering" technique, which involves gathering together similar data into a cluster to permit a significant generalization.

This paper describes a number of methods which make use of IBM 7090 computer programs to do clustering. A medical research problem is used to illustrate and compare these methods.

A Vestigial-Sideband, Phase-Reversal Data Transmission System *by D. L. Critchlow, R. H. Dennard, and E. Hopner, p. 33.* A new method of carrier retrieval is described for a suppressed-carrier, vestigial-sideband data transmission system. Tests over voice grade telephone lines indicate that operation at 3000 bits per second (in some cases, 3600 bps) can be obtained reliably over private lines with simple adjustable equalization, whereas fixed compromise equalization will allow speeds up to 2400 bps over a large percentage of lines in the switched network. The possibility of higher speed operation using a multilevel data signal is demonstrated by tests at 6000 and 8000 bps over a carefully equalized private line.

Nondestructive Determination of Thickness and Refractive Index of Transparent Films *by W. A. Pliskin and E. E. Conrad, p. 43.* A simple nondestructive method of measuring the refractive index and thickness of transparent films on reflective substrates has been developed. The technique involves the use of a microscope equipped with a monochromatic filter on the objective and a stage that can be rotated so that the reflected light is observed at various angles. The film thickness, d, is given by $d = [\Delta N\lambda]/[2\mu(\cos r_2 - \cos r_1)]$, where λ is the wavelength of the filtered light, μ is the refractive index, and ΔN is the number of fringes observed between the angles of refraction r_2 and r_1.

This technique is especially suited for films thicker than one micron. Techniques are also described for obtaining accurate thicknesses of films less than one micron by the combined use of monochromatic filters and an interference pattern chart. These techniques can be used to determine film thicknesses ranging from several hundred angstroms to several microns with accuracies of 0.2% on films thicker than 2μ, and accuracies of tens of angstroms on thinner films. Since visual comparisons of color can be used fairly easily for film thickness determinations, the techniques were used to construct a color chart for thermally grown SiO_2 films up to 1.5μ thick.

Transmission-Line Response Using Frequency Techniques *by C. L. Bertin, p. 52.* Frequency-domain analysis of transmission-line pulse response is presented. A computer program is used to evaluate the response, using subroutines to describe the line characteristics and terminal conditions. The program is applicable to lines of any cross section in which the TEM mode of propagation exists. The line characteristics are obtained from either formula prediction or frequency measurements on small samples. Because of skin effects or complex geometry, these characteristics can be extremely difficult to calculate, and so an experimental procedure is adopted for determining these parameters. The computer-program results are compared to measured values.

A Fast, Digital-Indexed Light Deflector *by W. Kulcke, T. J. Harris, K. Kosanke, and E. Max, p. 64.*

A Note on a Class of Binary Cyclic Codes Which Correct Solid-Burst Errors *by A. D. Wyner, p. 68.*

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Foreword: The IBM System/360 *by A. L. Samuel, p. 86.*

Architecture of the IBM System/360 *by G. M. Amdahl, G. A. Blaauw, and F. P. Brooks, Jr., p. 87.* The architecture of the newly announced IBM System/360 features four innovations:

1. An approach to storage which permits and exploits very large capacities, hierarchies of speeds, read-only storage for microprogram control, flexible storage protection, and simple program relocation.

2. An input/output system offering new degrees of concurrent operation, compatible channel operation, data rates approaching 5,000,000 characters/second, integrated design of hardware and software, a new low-cost, multiple-channel package sharing main-frame hardware, new provisions for device status information, and a standard channel interface between central processing unit and input/output devices.

3. A truly general-purpose machine organization offering new supervisor facilities, powerful logical processing operations, and a wide variety of data formats.

4. Strict upward and downward machine-language compatibility over a line of six models having a performance range factor of 50.

This paper discusses in detail the objectives of the design and the rationale for the main features of the architecture. Emphasis is given to the problems raised by the need for compatibility among central processing units of various size and by the conflicting demands of commercial, scientific, real-time, and logical information processing. A tabular summary of the architecture is shown in the Appendices.

Solid Logic Technology: Versatile, High-Performance Microelectronics *by E. M. Davis, W. E. Harding, R. S. Schwartz, and J. J. Corning, p. 102.* A new microelectronics packaging technique, called Solid Logic Technology (SLT), utilizes silicon planar glass-encapsulated transistors and diodes, and graphic arts techniques for producing high-quality, passive components having tight tolerances. The result is a process permitting the low-cost realization of a variety of versatile, high-performance circuit modules.

The salient features of SLT are described: the unique form of the semiconductor devices, the module fabrication process, and some performance results. In addition, insight is provided to the range of components that my be fabricated with this technology, i.e., inductors, capacitors and high-power transistors. Examples are shown of specific high-speed, high-density and complex circuit packages.

Design of Serviceability Features for the IBM System/360 *by W. E. Carter, H. C. Montgomery, R. J. Preiss, and H. J. Reinheimer, p. 115.* This paper discusses the design of features that are intended to provide the IBM System/360 with a significant improvement in serviceability over that of previous systems. It was decided from the beginning to develop the System/360 as an integrated package of hardware, operational programs, and maintenance procedures.

The major problems to be solved in gaining this improvement and integration were (a) reducing the maximum duration of service calls; (b) reducing the median duration and mean duration of service calls; and (c) matching a single package of maintenance programs and procedures to a large variety of operational monitor programs and machine models.

These problems have been attacked by supplementing standard servicing facilities (both hardware and program) with (a) the ability to record automatically the complete, detailed, system environment at the instant of error discovery; (b) the ability to initialize the CPU to any arbitrarily specified state (either "legal" or "illegal"), to advance from this state by a specified number of machine cycles, and to compare the new state with a precomputed result state, much of this using circuits that are independent of those required for program sequencing; (c) a system of programs that can be integrated with the System/360 Design Automation to produce automatically the inputs, results, and location analyses that are required to exploit the capabilities described in (b); (d) a family of diagnostic monitor programs that attack directly the problem of matching maintenance procedures to machine models and operational monitor programs; and (e) a facility to retry failing CPU operations at the instruction level in the larger models, in addition to the usual retry at the program-segment level.

Solid Logic Design Automation *by P. W. Case, H. H. Graff, L. E. Griffith, A. R. LeClercq, W. B. Murley, and T. M. Spence, p. 127.* This paper describes the unique features of a set of IBM 7090 programs which provide design assistance to engineers who use Solid Logic Technology. These programs were applied in the design of the IBM System/360.

Instabilities of Current in III-V Semiconductors *by J. B. Gunn, p. 141.* A description is given of a newly discovered phenomenon which is observed when an electric field of a few thousand V cm^{-1} is applied to a homogeneous sample of *n*-type GaAs or InP. Above a well-defined threshold field, a time-dependent decrease in current is observed, which is largely independent of external circuit conditions. In long specimens this decrease is aperiodic, resembling random noise with a bandwidth of ~ 10^9 c/sec. In short specimens, coherent oscillations are observed whose period is equal to the transit time of electrons between the ohmic electrodes of the

structure. Frequencies over the range of 0.5–6.5 Gc/sec have been generated in this way, using experimental techniques which are described. Measurements of the efficiency of dc-to-rf conversion (from 1 to 2%), and of peak power outputs (up to 0.5 W), suggest that the new effect may have useful applications. Some diagnostic experiments are described and the results are discussed in terms of various possible mechanisms. Although the quantitative agreement with theory is poor it is concluded that the current instability may possibly be due to the amplification of lattice optical modes.

Evaluation of Spectrochemical Data Using Digital Techniques *by N. R. D. Åslund and B. T. Cronhjort, p. 160.* This paper describes how a digital computer was used in combination with an emission spectrometer to determine chemical compositions of some steels. A mathematical model describing the relations between the composition and the intensities of the spectral lines was derived and experimentally tested. Both overlapping and matrix effects were considered. The computer was also used to calibrate the instrument.

An Approach Towards Batch Fabricated Ferrite Memory Planes *by E. A. Bartkus, J. M. Brownlow, W. A. Crapo, R. F. Elfant, K. R. Grebe, and O. A. Gutwin, p. 170.* This paper describes a technique for the batch fabrication of ferrite memory arrays in which wire, previously coated with a thermoplastic, is formed into two orthogonally disposed sets of parallel wires. These grids are oriented between opposing molds having matched grooves filled with a fluid mixture of ferrite powder and thermosetting resin, in such a manner that one set of parallel wires coincides with the groove axes. After suitable curing this structure is released and heat treated to pyrolyze the organic materials and sinter the ferrite.

A yield study on 108 memory arrays produced in this manner resulted in a yield of 72.2% on pulse testing under simulated operating conditions and an over-all process yield of 36.1%. The paper concludes with a tabulation of electrical characteristics of the arrays and a brief discussion of the applicability of the technology to various modes of operation and its potential for high-speed (250 nsec magnetic cycle time) operation.

Some Theoretical Aspects of a Proposed Double Quantum Stimulated Emission Device *by P. P. Sorokin and N. Braslau, p. 177.* A double quantum stimulated emission device is proposed and some operating characteristics and relevant systems of materials are discussed.

Ruby Laser Q-Switching Elements Using Phthalocyanine Molecules in Solution *by P. P. Sorokin, J. J. Luzzi, J. R. Lankard, and G. D. Pettit, p. 182.*

The Crystal Structure of $CaPd_3O_4$ *by R. C. Wnuk, T. R. Touw, and B. Post, p. 185.*

An Existence Theorem for the BCS Integral Equation *by F. M. Odeh, p. 187.*

On Ordered Retrieval from an Associative Memory *by L. R. Johnson and M. H. McAndrew, p. 189.*

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Foreword *by P. J. Price, p. 214.*

Crystal Chemistry and Band Structures of the Group V Semimetals and the IV-VI Semiconductors *by M. H. Cohen, L. M. Falicov, and S. Golin, p. 215.* Some simple facts regarding crystal structures and semiconducting vs semimetallic behavior of the Group V elements and the related Group IV-VI compounds are summarized. The simple chemical interpretation of these facts (based on three perpendicular p-bonding orbitals) is reviewed. This picture is reinterpreted in terms of a simple pseudopotential band model, which provides a deeper basis for understanding the simple chemical notions. The results of various band structure calculations are presented in detail in order to make explicit the direct relation between band and bond pictures as well as between crystal structures and semimetallic vs semiconducting behavior. The calculations also provide information as to probable locations of valence and conduction band edges.

The Effective g-factor of Holes in Bismuth *by G. E. Smith, G. A. Baraff, and J. M. Rowell, p. 228.*

High Field Galvanomagnetic Effects in Bismuth *by J. J. Vuillemin, p. 232.*

Piezo-Resistance and Piezo-Hall Effect in Bismuth *by A. L. Jain and R. Jaggi, p. 233.*

Phonon Dispersion Curves in Bismuth *by J. L. Yarnell, J. L. Warren, R. G. Wenzel, and S. H. Koenig, p. 234.* Dispersion curves for phonons propagating in the trigonal direction in bismuth at room temperature and at 75K have been obtained in a neutron inelastic scattering experiment. Observed frequencies (units 10^{13} rad/sec) at 75K are as follows: at the zone center, $\omega_{TO} = 1.40 \pm 0.02$, $\omega_{LO} = 1.89 \pm 0.02$; at the zone boundary in the trigonal direction, $\omega_{TA} = 0.73 \pm 0.01$, $\omega_{LA} = 1.12 \pm 0.02$, $\omega_{TO} = 1.91 \pm 0.02$, $\omega_{LO} = 2.03 \pm 0.02$. At room temperature, the observed frequencies were about 1.5 percent lower. Data were also obtained for longitudinal phonons propagating in the binary direction at 75K. It is interesting to note that the splitting between the zone boundary frequencies for the optical and acoustic branches for each polarization is quite large. This splitting is difficult to understand if bismuth is thought of as a slightly distorted simple cubic lattice. The experimental results may be qualitatively understood if bismuth is considered to be made up of a series of double layers normal to the trigonal axis. The atoms in each double layer form a crinkled hexagonal net with strong, probably covalent, bonds between atoms. The

forces between atoms on adjacent double layers are relatively weak. This model is consistent with the easy cleavage of bismuth normal to the trigonal axis. Analysis of the trigonal dispersion curves in terms of a linear chain model indicates that there are significant forces connecting a given atom with atoms situated on the four planes on either side of it.

Transport Properties and Band Structure in Bismuth, Antimony and their Alloys *by J. J. Hall and S. H. Koenig, p. 241.* We shall interpret the galvanomagnetic properties of bismuth, antimony and the Bi-Sb alloy system in terms of bands of carriers known to exist in the pure semimetals. In our interpretation, the new carriers, presumed holes, observed by several investigators in antimony must have slightly warped oblate ellipsoidal energy surfaces to account for the galvanomagnetic data of Juretschke et al, rather than tilted ellipsoidal surfaces. These new holes, together with the well established holes in bismuth and the Shoenberg electrons in both bismuth and antimony, account for the anomalous Hall coefficients of antimony. Consideration of qualitative features of the nearly free electron model of Jones and Harrison suggests that a linear variation of the spatial potential upon alloying bismuth with antimony is sufficient to account for the considerable changes observed in the transport properties of the alloy system. This model also suggests that the conduction band minima in bismuth are located at different points in the Brillouin zone from those in antimony. Experimental support for these hypotheses is discussed.

Cyclotron Resonance and the Fermi Surface of Antimony *by W. R. Datars and J. Vanderkooy, p. 247.* A new series of cyclotron resonance experiments has been made on antimony which gave extended information on electron and hole cyclotron masses. Experiments were carried out with the magnetic field in the principal crystal planes of antimony at 1.5K and with 35 Gc/sec microwave radiation. The magnetic field of cyclotron resonance in certain regions was dependent upon the angle of tip of the magnetic field with respect to the metal surface. These effects were minimized by accurate alignment of the magnetic field along the sample surface. The carriers of two bands were observed. The cyclotron mass of one band, assumed to be the conduction band, was consistent with a tilted-ellipsoidal model for the energy surfaces. The cyclotron mass along the 1′ principal electron ellipsoid axis was measured from data in the binary-trigonal plane to be 0.215 m_0. The conduction band ellipsoids were found to have a tilt angle of 36° and mass tensor components: $m_{11} = 0.068\ m_0$, $m_{22} = 0.63\ m_0$, $m_{33} = 0.34\ m_0$, $|m_{23}| = 0.41\ m_0$. The data indicated three sets of warped ellipsoids for the valence band. The warped ellipsoids were found to have a tilt angle of 4° and mass tensor components: $m_{11} = 0.093\ m_0$, $m_{22} = 1.14\ m_0$, $m_{33} = 0.093\ m_0$, and $|m_{23}| = 0.082\ m_0$. The cyclotron masses of holes and the measurement of cyclotron resonance at limiting points of the Fermi surface indicated that the hole surfaces probably are deformed from an ellipsoid.

Growth and Transport Properties of Bi-Sb Single Crystal Alloys *by D. M. Brown and S. J. Silverman, p. 253.*

Energy Band Structure of Graphite *by J. W. McClure, p. 255.* The energy band structure of graphite is described in the region of the Fermi surfaces by the Slonczewski-Weiss model. The electron and hole Fermi surfaces are highly elongated and are aligned along the six Brillouin zone edges which are parallel to the trigonal axis of the crystal. The energy is a non-parabolic function of wavenumber and the Fermi surfaces are not ellipsoids. Galvanomagnetic, de Haas-van Alphen, and other experiments have established that: the band overlap is about 0.03 to 0.04 eV, the carrier densities of electrons and holes are each about 3×10^{18} cm^{-3} at low temperatures, the effective masses perpendicular to the trigonal axis are about 0.04 m_0 for electrons and 0.06 m_0 for holes, and the length-to-width ratio of the Fermi surfaces is about 12. The only important effect not included in the Slonczewski-Weiss model is the correlation of electron motion due to the coulomb interaction. Though this effect is expected to be important *a priori*, it is not yet clear if it causes important discrepancies between the predictions of the model and the experimental results.

The Fermi Surface of Graphite *by M. S. Dresselhaus and J. G. Mavroides, p. 262.* Recent magnetoreflection measurements in pyrolytic graphite have been interpreted using the magnetic energy levels obtained from the McClure-Inoue secular equation and the appropriate selection rules for interband transitions. Combining these results with those of the de Haas-van Alphen effect, the band parameters of the Slonczewski-Weiss model have been evaluated and the Fermi surface determined. The magnetoreflection experiment indicates considerable warping of the Fermi surface, particularly for holes. Further experiments to determine this warping more precisely are discussed.

Change in Fermi Surfaces of Graphite by Dilute Acceptor Doping *by D. E. Soule, p. 268.* The effect of doping graphite single crystals with the acceptor boron was studied in the dilute range from &ltequiv.0.1 ppm to 0.5% by measurements of the Hall effect and de Haas-van Alphen effect. The transition from a mixed electron and hole conduction in the narrow band overlap region (0.035 eV) to that of a single hole conduction produces a peak in the Hall coefficient that shifts to a lower boron concentration with a decrease in temperature. The increase in hole concentration is accompanied by a rapid decrease in mobility, demonstrating the importance of collision broadening. Preliminary de Haas-van Alphen results tentatively identify the major electron and hole Fermi surfaces by means of the period shift with increasing acceptor concentration. A *new*, very small ellipsoid-like Fermi surface was discovered. It is aligned along the hexagonal axis, having an anisotropy ratio of 9 with orbital masses of about 0.0023 m_0 for H *concat* C and 0.017 m_0 for H $\perp$ C. Analysis strongly indicates that this surface contains minority holes. Three of these surfaces are considered to be aligned

symmetrically like "outriggers" about the major hole surface, producing a total of six in the Brillouin zone. A comparison is made with the cyclotron resonance results and a possible interpretation of these minority Fermi surfaces is presented using the Slonczewski-Weiss band model.

STB Model and Transport Properties of Pyrolytic Graphites *by C. A. Klein, p. 274.*

Alfvén Wave Propagation in Bismuth: Quantum Oscillations of the Fermi Surface *by G. A. Williams and G. E. Smith, p. 276.* Alfvén wave propagation in single crystal bismuth has been studied as a function of magnetic field to 105 kilogauss for frequencies between 13 and 18 kMc/sec. Small deviations from a linear dependence of wave velocity on magnetic field are found and are interpreted as quantum oscillations in the mass density of carriers. Theory and experiment are compared for the magnetic field along a bisectrix axis and along a two-fold axis. Good agreement is found for the first case, but significant discrepancies exist for the magnetic field along a two-fold axis.

Infrared Reflectivity of Bismuth in the Quantum Limit *by L. C. Hebel, p. 284.*

Acoustic Plasma Waves in Semimetals *by A. L. McWhorter and W. G. May, p. 285.* The acoustic plasma wave suffers severe Landau damping for equal-temperature carriers obeying Boltzmann statistics, but can be relatively weakly Landau damped in semimetals if in the propagation direction the Fermi velocities and masses of the two carriers are very unequal. Only the carriers with the smaller Fermi velocity are important in producing collision damping since the other carriers store no appreciable momentum. Some results for many-valley semimetals like bismuth are given, together with a discussion of the problem of exciting and detecting this essentially neutral and longitudinal wave. Experiments undertaken to detect the acoustic plasma wave by transmission through thin wafers of bismuth at 10 Gc/sec have been unsuccessful thus far, but have revealed the existence of a higher velocity wave of weak amplitude that has not yet been identified. A discussion is also given of some magnetic quantum effects that should be associated with the acoustic wave.

Effect of the Self-Magnetic Field on Galvanomagnetic Effects in Bismuth *by S. Tosima and R. Hirota, p. 291.* The magnetoresistance and the Hall coefficient for pure bismuth at 77K have been calculated to the second order in the self-magnetic field, i.e. current density. The calculations show that the observed dependence of the galvanomagnetic effects on the current density at high currents can be qualitatively explained by the self-magnetic field. However, to obtain quantitative agreement it is necessary to include the contribution of diffusion currents in the calculation. The theory for the self-magnetoresistance, including diffusion, has been carried out for the pre-pinch regime of currents. The resulting curve for the self-magnetoresistance agrees well with the observed one if the scattering times between ellipsoids are taken to be of order 10^{-9} sec (assuming that the diffusion effects are not dominated by the surface, i.e. that the surface-recombination velocity is sufficiently small).

Non-Ohmic Conduction in Bismuth *by W. Schillinger, p. 295.* The experimentally determined I-V characteristics at large currents at 4.2K, 77K, and 300K have been found to be nonlinear in both single crystal and wire samples of bismuth. A theory has been formulated which includes self-magnetoresistance, a redistribution of carriers (pinch) and bimolecular bulk and surface recombination. Very little information exists, either experimentally or theoretically, with regard to these recombination mechanisms. A program has been written to numerically solve the equations for various values of the electron-hole recombination time and surface velocity. It is found that the I-V characteristics are dominated by the self-magnetoresistance and vary only slightly for a wide range of the generation-recombination parameters.

Linear and Nonlinear Methods in Pattern Classification *by H. J. Greenberg and A. G. Konheim, p. 299.* The problem of pattern classification has two highly interactive aspects: (1) the selection of numerical measurements to 'represent' the patterns, and (2) the specification of an algorithm to identify patterns, based upon the numerical values of these measurements. The present paper presents the mathematical framework for one attack upon these problems and gives results obtained in some experiments in character recognition.

Magnetically Controlled Variable Logic *by E. G. Newman and L. F. Winter, p. 308.* Magnetically controlled multipurpose logic provides a great flexibility and compactness. A matrix consisting of 2^n saturable magnetic elements for n variable inputs is controlled by an adjacent magnetic pattern recorded on a magnetic medium, which determines the logical function to be performed. Since 2^{2n} magnetic patterns enable the performance of 2^{2n} logical functions, great flexibility of system operation is possible. The selection of the required magnetic materials is described.

Application of the basic system to several special purpose machines is shown. In particular, the design of a computer using microprogramming techniques is described, and the application of this system to various serial and parallel computer operations is discussed.

A New Digital Method of Bit Synchronization Derived from an Analog Theory *by A. J. Anello, A. C. Ruocchio, and W. D. Van Gieson, Jr., p. 318.* This paper discusses a new method of bit synchronization derived from an analog theory to solve the problems involved in receiving a serial train of bits from a remote data communication source. Test results show that accurate frequency and phase information can be derived from the received serial data. The Analog Derived Clock to accomplish this bit synchronization is described, and

applications in two-wire (half duplex operation) and four-wire (full duplex operation) communication systems are discussed. Speeds up to 2 Mc/sec using existing digital circuit technology were achieved. The special advantage of the Analog Derived Clock over present clocking techniques is an increase in speed and a reduction in circuitry.

Simulation of a Hydraulic Actuator *by A. H. Mitchell and K. L. Johnson, p. 329.* A simple mathematical model of a hydraulic actuator is formulated, and the differential equations describing the model are derived. Experimental data and a computational solution of the model are determined. Results correspond favorably with oscilloscope velocity traces; hence the model could serve a useful purpose in mechanical design.

A Note on the Resonant Modes and Spatial Coherency of a Fabry-Perot Maser Interferometer *by G. J. Y. Fan, p. 335.*

Analysis of a Nondegenerate Two-Photon Giant-Pulse Laser *by R. L. Garwin, p. 338.*

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Surface Effects on Silicon: Introduction *by D. R. Young and D. P. Seraphim, p. 366.*

Space-Charge Model for Surface Potential Shifts in Silicon Passivated with Thin Insulating Layers *by J. E. Thomas, Jr. and D. R. Young, p. 368.* Semipermanent changes in the semiconductor surface potential occur in insulator-covered semiconductors when external fields are applied for long times, particularly at elevated temperatures. An attempt to explain these changes in terms of the charging and discharging of interface states leads to conclusions that disagree with many of the experimental facts. Specifically, the semipermanent effects of interface-state charges can always be overcome by the application of a field smaller than that which is used to induce the effect, and of the same sign, while the experiments described in the accompanying papers generally show that a field much larger than the inducing field, and of the opposite sign, is required to return the insulator covered surface to its initial status. The accumulation of space charge in the insulating layer can give rise to very large fields at the semiconductor surface that persist after the removal of an external inducing field. The size and sign of such space-charge fields agree with the experimental observations. Measurements made after treatment at temperatures above 125°C show that the surface of silicon passivated with silicon dioxide can become strongly *n*-type as a result of such a positive space-charge layer formed at the interface. A model is presented based on the concept that this space charge arises from oxygen vacancies in the silicon dioxide. It is suggested that the improvement resulting from the use of phosphorus pentoxide on the outside surface is due to the elimination of vacancies by the oxidizing action of the phosphorus pentoxide.

Stabilization of SiO_2 Passivation Layers with P_2O_5 *by D. R. Kerr, J. S. Logan, P. J. Burkhardt, and W. A. Pliskin, p. 376.* Measurements are reported on the stability of planar, *npn* silicon transistors with and without a phosphosilicate glass layer over the SiO_2 passivation layer. The phosphosilicate layer forms during the emitter diffusion from a P_2O_5 source, and the data show that, to insure stability, it must not be removed in subsequent processing steps. The units tested were of conventional geometry except for a gate electrode over the base region, which provided additional information on the surface condition. The transistors were subjected to temperatures of 150° and 200°C with either gate-bias or junction reverse-bias. Production transistors, without gates, which had failed on life test were shown to have no phosphosilicate layer because it had been removed by excessive etching during fabrication. Additional evidence for the stabilization by P_2O_5 has been obtained using metal-oxide-silicon capacitors with and without P_2O_5 treatment of the SiO_2 layer. Both dc conduction through the insulator and stability of the capacitance-voltage characteristic were measured. These experiments suggest that the transistor degradation with unstabilized SiO_2 is caused by an accumulation of positive space-charge in the silicon-dioxide. This charge accumulates when an electric field (directed toward the silicon) is applied to the SiO_2 at temperatures in the range of 150°C.

Effect of Temperature and Bias on Glass-Silicon Interfaces *by D. R. Kerr, p. 385.* New technologies for deposition of thin glass films on silicon substrates have generated interest in the resulting glass-silicon interface potentials and the interface stability under conditions of bias and temperature that might be experienced in device operation.

Experiments are described which show accumulation of space-charge layers at glass-silicon interfaces under combined conditions of electric field applied normal to the surface, and elevated temperature. The glasses studied are lead-alumino-borosilicates and zinc-alumino-borosilicates and were applied in films several microns thick by sedimentation techniques. Measurements were made on metal-glass-silicon capacitor structures. The silicon at the interface may be shifted strongly *n*-type or strongly *p*-type, depending on applied field direction, during a heating cycle of a few minutes. Surface charge densities up to 10^{13} electronic charges/cm^2 have been observed. The temperatures required for such shifts vary over the range 100° to 300°C, depending on glass composition. Conductivity through the films during the combined bias-temperature treatment is compared with interface charge build-up. The data suggest a mechanism in which the bias-temperature combination causes movement of ions (possibly sodium) with a resultant build-up of space charge in the glass near the interface. The long-term stability of this "locked-in" charge indicates that interface potential with the more stable glasses may be permanently tailored to a desired value by bias-temperature treatment.

Electrode Control of SiO_2 Passivated Planar Junctions *by P. P. Castrucci and J. S. Logan, p. 394.* Electric fields have been applied to the surface over a planar silicon junction by means of a metallic control-ring electrode on the oxide surface. Capacitance measurements have indicated that a large, positive, immobile charge is present at or near the interface between the silicon dioxide and the silicon. An improvement in breakdown voltage occurs when the control ring is biased negatively, producing a field that opposes the field of the immobile charge. Positive control-ring voltages are shown to produce very large junction leakage currents. The leakage current is shown to be sensitive to a high-temperature reverse bias treatment and a model for this effect is suggested. Transistors with base contracts that extend over the oxide-protected collector junction are shown to have higher breakdown voltages than do those that lack the base electrode extension. This effect is consistent with the improvement in breakdown voltage found in control-ring diode measurements.

Electrochemical Phenomena in Thin Films of Silicon Dioxide on Silicon *by D. P. Seraphim, A. E. Brennemann, F. M. d'Heurle, and H. L. Friedman, p. 400.* A study has been made of the effect of chemical additives and of annealing and electrical biasing procedures upon the state of charge of silica films grown on silicon. A model, proposed to account for the observations, is based on the assumption that phosphorus, aluminum, and boron, when present, substitute for Si in SiO_2. The resulting species may be represented as PO_2+, PO_2-, AlO_2-, or BO_2-. The mobile charge carrier in the silica under the conditions investigated here is assumed to be an oxide-ion vacancy. Under certain conditions electrolysis is accompanied by deviations from Faraday's laws and changes the net charge in the oxide; under other conditions only the charge distribution in the oxide is changed. The experiments leading to the development of the model, which were done with metal-oxide-silicon structures, have been supplemented with experiments with field effect transistors. Field effect transistors of the *n-p-n* type have been made to operate in the enhancement mode.

Carrier Surface Scattering in Silicon Inversion Layers *by F. Fang and S. Triebwasser, p. 410.* The field effect surface-channel conductance and transconductance of both *p*-type and *n*-type Si inversion layers were measured as a function of external field. In the small signal region, the channel conductance was found to vary logarithmically with the transverse field. The results are interpreted in terms of reduction of carrier mobility that is due to surface scattering. A model which consists of a uniformly distributed charge layer and self-consistent field is proposed to explain the observed results. It was found that in most samples measured a combination of specular and diffuse scattering is involved. Examples of completely diffuse scattering as well as the diffuse and specular combination are given. The temperature dependence of the surface mobility between 77K and 300K is presented.

Effect of Low Temperature Annealing on the Surface Conductivity of Si in the Si-SiO_2-Al System *by G. Cheroff, F. Fang, and F. Hochberg, p. 416.* Studies on insulated-gate field effect devices fabricated on both *n*- and *p*-type Si have shown the existence of inversion layers on *p*-type surfaces and of accumulation layers on *n*-type surfaces. The degree of inversion or accumulation was characterized by measuring the total series capacity of the SiO_2 gate and the underlying Si as a function of an applied dc potential. The initial surface conductivity, as measured by the source to drain conductance g_{sd} at zero gate bias, indicates that most of the surface charge is immobile. Prolonged heat treatments at 350°C on *p*-type substrates have resulted in a two order-of-magnitude increase in g_{sd} accompanied by little or no change in the total surface charge density N_i. On *n*-type substrates, however, the same treatment results in a factor of 5 decrease in N_i. The effects of these treatments on the surface uniformity as well as on appropriate device parameters are reported.

Chemical and Ambient Effects on Surface Conduction in Passivated Silicon Semiconductors *by H. S. Lehman, p. 422.* The effect of processing variables on the surface conduction properties of passivated silicon junction devices has been studied. Insulated gate field-effect transistors fabricated in *p*-type silicon were used as an experimental tool. Varying the metal used as the gate electrode is shown to strongly influence the surface conductivity of the field-effect device. The effects of heat treatments in various ambients and variations in the insulators used are also discussed. Surface conduction is shown to be a complex function of materials, thermal history and processing.

Hall Measurements on Silicon Field Effect Transistor Structures *by A. B. Fowler, F. Fang, and F. Hochberg, p. 427.*

Velocity of Sound in a Many-Valley Conductor *by E. Adler, p. 430.* The effect on the velocity of sound corresponding to the "Keyes effect," for nonzero frequency and finite wavelength, is calculated by means of the electron Boltzmann equation. The result may be expressed as an effective electronic contribution to the elastic constant; the deviation, ${}_{\chi}dK_0$ of δK from the Keyes electronic contribution to the elastic constant, δK_0, is examined as a function of frequency and other parameters. When the Fermi velocity v is much larger than the sound velocity s and the mean free path is of the same order or larger than the acoustic wavelength, we find that $\chi \approx (s/v)^2$. When the mean free path is small compared to wavelength, $\chi = \omega^2/[\omega^2 + (\nu + 1/\bar{\tau}_d)^2]$, where ν is the intervalley scattering rate and $\bar{\tau}_d$ is an average diffusion relaxation time.

Displacement Discontinuity over a Transversely Isotropic Elastic Half-Space *by W. T. Chen, p. 435.* The paper presents a solution to the elasticity problem where the discontinuity is in the displacement component parallel to the plane area

inside the transversely isotropic medium. The work previously performed on discontinuity problems is also discussed.

The Design of Transformer (Dimond Ring) Read-Only Stores *by D. M. Taub and B. W. Kington, p. 443.* The operation of transformer read-only stores is explained and the main methods of construction described. The optimum turns ratio of the transformers is calculated. It is shown how a transformer can produce an output current even though the energised word line is not threaded through it. The value of this ZERO current depends on the information pattern and is found to be greatest with one of two patterns, depending on the type of construction used. For both patterns, expressions for the maximum ZERO and minimum ONE output signals are derived.

The cause of resonances is explained and a method of damping described. The expressions for optimum turns ratio, maximum ZERO and minimum ONE output signals are modified to take account of the damping and a worked example is given. Computed and observed output waveforms are compared for a store containing a non-worst-case pattern and are found to agree well.

The Equilibrium Behavior of the Silicon-Hydrogen-Chlorine System *by R. F. Lever, p. 460.* The composition of the gas phase is calculated for various temperatures, pressures, and chlorine-to-hydrogen ratios for the two-phase system consisting of solid silicon in equilibrium with the gas phase. It is shown that in the range of variables most frequently used for vapor growth of silicon, the principal species under equilibrium conditions are H_2, HCl, $SiHCl_3$, and $SiCl_2$.

Stability Criteria for Large Networks *by R. K. Brayton, p. 466.* An arbitrarily large network of bistable tunnel diode switching circuits is analyzed for stability. One condition derived indicates that increasing the total "fan" of each circuit might tend to make the whole network unstable. This condition is independent of the tunnel-diode characteristic. Another condition is also derived which depends on this characteristic but does not involve the total "fan". Finally, two general theorems which were proved in another paper are stated and discussed in terms of their applicability to certain classes of large networks and the types of conditions for stability that can be obtained.

Mutually Quenched Injection Lasers as Bistable Devices *by G. J. Lasher and A. B. Fowler, p. 471.*

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A Statistical Approach to the Design of Diffused Junction Transistors *by D. P. Kennedy, P. C. Murley, and R. R. O'Brien, p. 482.* Monte Carlo methods of statistical analysis are applied to the problems of transistor design and optimization. The experimental tolerances associated with any diffusion process are shown to represent an important factor in the initial design of diffused junction transistors. Many transistor parameters exhibit a substantial degree of sensitivity to small variations in the diffusion process. This is confirmed by a comparison between the theoretical and experimental open-base breakdown voltage, and current gain, for a large number of devices. It is therefore proposed that the design of a transistor be based upon attaining a specified set of electrical characteristics when the device is assumed to be fabricated by a non-ideal diffusion process. An electronic computer has been used in an investigation of the foregoing problem. The investigation shows further that a margin-of-safety must be designed into each electrical parameter of a transistor to assure that the resulting device satisfies a given set of design specifications, even though this margin-of-safety may differ for each parameter. In this paper examples are presented to illustrate the theoretical trade-off between several opposing transistor parameters that exhibit a substantial degree of variability due to a non-ideal diffusion process.

Calculation of the Capacitance of a Semiconductor Surface, with Application to Silicon *by P. M. Marcus, p. 496.* The electrostatic problem of finding the surface capacitance of a plane semiconductor surface as a function of applied voltage is formulated and solved. The solution takes account of the space charge distribution in the semiconductor, of a surface dielectric layer, of the possible presence of surface states, and of the exact Fermi-Dirac statistics for the charge carriers. The macroscopic electrostatic problem and microscopic electronic description are kept separate, convenient reduced units are introduced, and the differential capacitance characteristic is expressed in a simple parametric form. For bands of normal form, and for a single-level acceptor or donor surface state, the reduced characteristic depends on eight reduced quantities for general statistics, and on six for the simpler Boltzmann limit; the latter include three quantities describing the surface state level, one for the dielectric layer, one bulk semiconductor parameter, and one contact potential constant which shifts the voltage scale. Explicit calculations are made for silicon at 293K for various doping levels, dielectric layers, and single-level surface states; the variation of the characteristic dip in the capacitance is exhibited as a function of these parameters.

Design of ACP Tunnel-Diode-Coupled Circuits *by D. W. Murphy and J. R. Turnbull, p. 506.* The performance of the Advanced Circuit Program (ACP) circuits described by D. H. Chung and J. A. Palmieri can be improved by replacing the coupling resistor with a pair of tunnel diodes. The low impedance and power gain properties of the tunnel diode increase the fan-power and provide better control of signal levels. In addition, the improved rise times increase circuit speeds to the extent that delays of less than 1 nsec per logic function have been demonstrated. Since the tunnel diode pair can be designed to perform AND, OR, or majority logic

functions, the logic flexibility of these circuits is greater than that of the resistor-coupled circuits. The design techniques which lead to a consistent set of logic circuits and to binary full adders are discussed.

The very fast rise times generated by the tunnel diode pair require the use of transmission lines as the interconnection medium. The techniques used to minimize the effects of noise and reflections on circuit performance are discussed.

Computer Analysis of Electron Paramagnetic Resonance Spectra *by J. D. Swalen and H. M. Gladney, p. 515.* Algebraic methods that are useful in the reduction of EPR spectra to the magnetic parameters in the phenomenological Hamiltonian are summarized and programs presently available to accomplish the necessary computations are described. Among the topics discussed are (i) the calculation of the spectrum of the complete spin Hamiltonian for single-crystal experiments, with the principal axis system; (ii) the transformation of the Hamiltonian to the magnetic quantization axes, which is convenient for perturbation theory; (iii) the use of iteration methods to determine the parameters by a least-squares technique; (iv) the detailed fitting of EPR spectra of polycrystalline or glassy-state magnetic sites; (v) the correlation methods in the analysis of solution spectra; (vi) a novel integral transformation to improve the resolution; and (vii) the calculation of the dipolar sum for line width studies.

Glass-Passivated GaAs Chip Tunnel Diode *by S. S. Im, J. H. Butler, and D. A. Chance, p. 527.* A novel approach to the fabrication of tunnel diodes described. The experimental tunnel diode is a gallium arsenide planar device, using a conventional alloyed junction in an epitaxially grown GaAs substrate, and hermetically sealed by a high-temperature glass coating. The tunnel diode is fused to a circuit module using a solder reflow method. This package provides a high degree of mechanical reliability, great reduction in size, and an easy means of interconnection. Another unique feature is that the peak current is tailored electrically to within 1% by altering the impurity distribution near the junction, rather than by the conventional electrochemical etching technique. The resulting gallium arsenide tunnel diodes, having peak currents of 8 mA and capacitances of 5 pF, are suitable for use in a one-nanosecond switching circuit.

Thermal Limitations on the Energy of a Single Injection Laser Light Pulse *by G. J. Lasher and W. V. Smith, p. 532.* The upper limits on the output pulse power of an injection laser arising from heating effects are estimated. The heat is assumed to be dissipated by conduction through a large homogeneous body. A simple method for computing over-all diode efficiency is given.

Derivation of Maximal Compatibles Using Boolean Algebra *by M. P. Marcus, p. 537.*

Negative Resistance Tunnel Diodes in Silicon Carbide *by R. F. Rutz, p. 539.*

High Power CW Operation of GaAs Injection Lasers at 77° K *by J. C. Marinace, p. 543.*

Continuous Microwave Oscillations of Current in GaAs *by N. Braslau, J. B. Gunn, and J. L. Staples, p. 545.*

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Ab Initio Computations in Atoms and Molecules *by E. Clementi, p. 2.* The present status of *ab initio* computations for atomic and molecular wave functions is analyzed in this paper, with special emphasis on the work done at the IBM Research Laboratory, San Jose. The Roothaan-Hartree-Fock method has been described in detail for atomic systems. A systematic tabulation of atomic Hartree-Fock functions has been made available in an extended supplement to this paper. Techniques for computing many-center, two-electron matrix elements have been discussed for Slater or Gaussian basis sets. It is concluded that the two possibilities are comparable in efficiency. We have advanced a few suggestions for the extension of the self-consistent field technique to macromolecules. The validity of the suggestions have not been tested.

Following the Bethe and Salpeter formalism, the relativistic correction has been discussed and illustrated with numerical results for closed-shell atoms. A brief analysis of the relativistic correction for molecular systems shows that the relativistic effects cannot be neglected in ionic systems containing third-row atoms.

The correlation energy is discussed from an experimental starting point. The relativistic and Hartree-Fock energies are used for determining the correlation energy for the elements of the first three periods of the atomic system. A preliminary analysis of the data brings about a "simple pairing" model. Data from the third period force us to consider the "simple pairing"model as a first-order approximation to the "complex pairing" model. The latter model is compared with the geminals method and limitations of the latter are pointed out.

A semiempirical model, where use is made of a pseudopotential that represents a coulomb hole, is advanced and preliminary results are presented. This model gives reason to some hope for the practical formulation of a Coulomb-Hartree-Fock technique where the correlation effects are accounted for and the one-particle approximation is retained.

Automatic Distortion Correction for Efficient Pulse Transmission *by K. E. Schreiner, H. L. Funk, and E. Hopner, p. 20.* Automatic correction of pulse distortion provides the prospect for materially extending the efficiency of data communications over telephone networks. Systems that will compensate automatically for deficiencies in the phase and amplitude characteristics of a transmission channel are shown to be technically feasible. Two specific systems are demonstrated: The first, a "time-reversal" system, compensates for distortion in the phase characteristic only, and the second, a "time-domain" system, compensates for distortion in amplitude as well as phase. The theoretical basis of this work is presented and verified by experimental results obtained on simulated lines and on common-carrier channels.

Active Image Formation in Lasers *by W. A. Hardy, p. 31.* An optical cavity is described in which the modes are determined as stationary states of the diffraction-limited object/image transformation of classical optics; these modes are selected by the insertion of controls into the optical cavity and lead to field distributions which image these controls. When the cavity is driven by an active medium, laser oscillation can occur, and this is discussed in terms of the coupled mode equations used by Wagner and Birnbaum in their theory of quantum oscillation in a multimode cavity. Some properties of these modes in the limits of small and large optical aperture are described and illustrated with experiments using the helium-neon gas laser.

On Relations Defined by Generalized Finite Automata *by C. C. Elgot and J. E. Mezei, p. 47.* A transduction, in the sense of this paper, is a n-ary word relation (which may be a function) describable by a finite directed labeled graph. The notion of n-ary transduction is co-extensive with the Kleenean closure of finite n-ary relations. The 1-ary transductions are exactly the sets recognizable by finite automata. However, for $n > 1$ the relations recognizable by automata constitute a proper subclass of the n-ary transductions. The 2-ary length-preserving transductions constitute the equilibrium (potential) behavior of 1-dimensional, bilateral iterative networks. The immediate consequence relation of various primitive deductive (respectively computational) systems, such as Post normal systems (respectively Turing machines) are examples of transductions. Other riches deductive systems have immediate consequence relations which are not transductions. The closure properties of the class of transductions are studied. The decomposition of transductions into simpler ones is also studied.

Amplification of Sound by Hot Electrons *by P. J. Price, p. 69.*

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Hazard Detection in Combinational and Sequential Switching Circuits *by E. B. Eichelberger, p. 90.* This paper is concerned with a unified approach to the detection of hazards in both combinational and sequential circuits through the use of ternary algebra. First, hazards in a combinational network resulting from the simultaneous changing of two or more inputs are discussed. A technique is described that will detect hazards resulting from both single- and multiple-input changes. The various types of hazards connected with gate-type sequential circuits are also discussed, and a general technique is described that will detect any type of hazard or race condition that could result in an incorrect terminal state. This technique could be easily implemented in a computer program which would be capable of detecting hazards in circuits containing hundreds of logic blocks.

Coincidence Counter Models with Applications to Photographic Detection Theory *by H. J. Zweig and D. P. Gaver, p. 100.* Various types of counter models have been treated in the literature over the past twenty years. In all these models the counter mechanism involves a fixed or random dead time following a registered event. In this paper a different type of counter mechanism is introduced in which the occurrence of two or more input events within a relatively short time is required to produce a registered (output) event. This model of an "*R*-fold coincidence counter" is applied to the development of grains in a photographic emulsion for both low-intensity and high-intensity reciprocity failure.

On Plane Blazed Gratings *by E. S. Barrekette and R. L. Christensen, p. 108.* The Fraunhofer patterns of blazed gratings are derived on the basis of a scalar theory which includes the non-linear dependence of the obliquity factor and the phase modulation on the spatial frequencies defining the positions of the source and of the observer. The solution based on the usual 'linear communications' theory is compared with one based on the more general non-linear theory; it is shown that the former is meaningful only in the neighborhood of the blaze wavelength. The behavior of blazed gratings is examined in the light of non-linear theory in the region away from the blaze wavelength. It is shown that the envelope function describing the amplitude distribution due to a single groove depends on the single parameter defining half the phase difference between the two edges of a single diffracting facet. It is also shown that certain wavelengths are missing from the zero order and that 'dark' lines exist into which no light of any order is transmitted. A useful maximum for the aspect ratio is derived. The Littrow and spectrograph configurations are examined in some detail.

Demagnetization of Flat Uniaxial Thin Films Under Hard Direction Drive *by H. J. Kump, p. 118.* The demagnetizing fields are derived for all points of flat uniaxial thin films under various drive fields. The derivation is accomplished by breaking up the flat film into a number of sheets in superposition and integrating their individual contributions to the demagnetizing fields. The scheme is self-consistent in that the magnetization results as a consequence of the derivation, and need not be assumed. Further, the accuracy does not depend on the position with respect to the edges, but rather on the number of sheets.

The general approach to the problem is discussed briefly and the final equation for a rectangular geometry given. The discussion is concerned with one-dimensional examples, demonstrating the somewhat unexpected form of the demagnetizing fields under various hard axis drive conditions. Single bits as well as continuous films of Permalloy driven by uniform fields and multiple strip lines are treated. The effect of registration on the demagnetization is also discussed.

Average Motion Times of Positioners in Random Access Devices *by F. R. Hertrich, p. 124.* An analysis is made of the average motion times of mechanical positioners based on trapezoidal velocity vs time curves. The results are plotted in terms of dimensionless motion parameters. It is shown that average motion time may be optimized by balancing acceleration and velocity in a proper way. The selection of optimum transmission ratios between motor and load is discussed and demonstrated in an example.

Sheet Thermoforming of a Superplastic Alloy *by D. S. Fields, Jr., p. 134.*

A New Method for Frequency-Division Multiplexing, and Its Integration with Time-Division Switching *by P. M. Thrasher, p. 137.*

Electrodeposition of Stress-Insensitive Ni-Fe and Ni-Fe-Cu Magnetic Alloys *by C. LeMéhauté and E. Rocher, p. 141.*

Peculiar Domain Behavior in Thin, Magnetic Ni-Fe Double Films *by S. Middelhoek, p. 147.*

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Fresnel Holograms: Their Imaging Properties and Aberrations *by J. A. Armstrong, p. 171.* A simple and unified treatment is given of the properties of the magnified or demagnified images reconstructed from Fresnel holograms. The resolution attainable in wavefront reconstruction is discussed with particular attention to the aberrations of reconstructed images. Explicit expressions are given for the five primary wave aberrations, viz., spherical aberration, coma, astigmatism, curvature of field, and distortion.

Analysis of the Impurity Atom Distribution Near the Diffusion Mask for a Planar *p-n* Junction *by D. P. Kennedy and R. R. O'Brien, p. 179.* Presented here are the results from a mathematical investigation of the impurity atom distribution within a planar *p-n* junction. Two fundamentally different diffusion processes are considered: In the first, a constant impurity atom concentration is maintained at the semiconductor surface; in the second, a fixed quantity of impurity atoms is involved in the entire diffusion process. The results of this investigation show than a one-dimensional approximation inadequately characterizes the impurity atom distribution within a planar junction, and that in theory, the planar junction is not at a constant distance from its impurity atom source. Instead, the junction is closer to its source at the semiconductor surface than deep within the bulk material. Further, it is shown that when diffusion takes place from a source of constant concentration density, the junction impurity atom gradient is maximum at the semiconductor surface. In contrast, this junction impurity atom gradient is shown to exhibit a minimum at the semiconductor surface when the total number of impurity atoms is time invariant throughout the entire semiconductor material.

Some Numerical Experiments in the Theory of Polynomial Interpolation *by F. W. Luttmann and T. J. Rivlin, p. 187.* An important unsolved problem in the theory of polynomial interpolation is that of finding a set of nodes which is optimal in the sense that it leads to minimal Lebesgue constants. In this paper results connected to this problem are obtained, and some conjectures are presented based upon numerical evidence garnered from extensive computations.

On a Circular Crack in a Transversely Isotropic Elastic Material Under Prescribed Shear Stress *by W. T. Chen and R. P. Soni, p. 192.*

Chain Matrices and the Crank-Nicolson Equation *by H. P. Flatt, p. 196.*

A Drive Scheme for the GaAs-Si Light-Activated Switch *by P. Polgar, M. M. Roy, and T.-H. Yeh, p. 200.*

Mapping an Arbitrary Range into (–1, 1) with a Side Condition: Application to Numerical Quadratures *by A. D. McLean and M. Yoshimine, p. 203.*

A New Technique for Dynamic Analysis of Acoustical Noise *by R. H. Peterson and R. L. Hoffman, p. 205.*

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On Communications and Data Processing: A Foreword *by M. C. Andrews, p. 226.*

A New Approach to Time-Domain Equalization *by E. Gorog, p. 228.* A theoretical study is made of the time-domain equalization procedures for the correction of delay distortion in high-speed data transmission lines. In the first part of the paper the conditions that insure valid and effective use of a class of conventional time-domain equalizers are reviewed. In the second part of the paper, a new type of nonlinear time-domain equalizer is proposed, in which iterative methods are not required. The theoretical basis is given for the new equalization method.

Decoding of Cyclic Codes Using Position Invariant Functions *by J. D. Ullman, p. 233.* Ratios that are sufficient to detect classes of error patterns in cyclic codes are discussed. Systematic procedures for the correction of Bose-Chaudhuri codes are given; it is shown that these are quite fast but practical only for small numbers of random errors. It is seen that there is the capability of simultaneous independent and burst error correction.

A Comparison of Pseudo-Noise and Conventional Modulation for Multiple-Access Satellite Communications *by H. Blasbalg, p. 241.* This paper compares pseudo-noise (PN) with conventional modulation techniques for multiple-access satellite communications of voice messages. The reference for all comparisons is the conventional frequency-division multiplex telephone system. The comparison study is concerned with theoretical channel parameters as well as practical considerations which are unique to satellite communications. For PN modulation, curves are presented which show the relationship between the intrinsic signal-to-noise ratio and the number of channels per megacycle for a given test-tone-to-noise ratio.

It is concluded that high quality voice transmission can be achieved efficiently with PN-multiplexing. In particular, pulsed pseudo-noise transmission with some form of wide-deviation pulse-time message modulation and matched filter reception uses the down-link intrinsic signal-to-noise ratio and bandwidth as efficiently as the conventional single-sideband up and composite frequency-modulation with feedback down, provided that up-link power control is used. For lower quality communications, conventional modulation is more efficient in rf bandwidth utilization. Where rf bandwidth is not a significant factor, but the down-link intrinsic signal-to-noise ratio is important, then in the case of PN modulation, communications can be made thermal noise limited in the down-link. Here PN is, for all practical purposes, as efficient as orthogonal multiplexing.

A Pulsed Pseudo-Noise VHF Radio Set *by F. Corr, R. Crutchfield, and J. Marchese, p. 256.* The design of a radio set using pulsed pseudo-noise signals is described. The unit uses pulse position modulation and matched-filter detection. The use of pulse compression techniques permits the radio to achieve good signal detectability; it also permits privacy for each of several sets operating in a common channel. Characteristics of the 280 Mc/sec rf system are given and the call-up logic for achieving telephone-like operation is described. Some aspects of the digital matched filter design are discussed. Analysis of theoretical operation shows only a small performance difference between digital and linear matched filters.

Analysis and Simulation of a Digital Matched Filter Receiver of Pseudo-Noise Signals *by R. Van Blerkom, R. E. Sears, and D. G. Freeman, p. 264.* This paper discusses the performance of a digital matched filter receiver matched to a biphase-modulated signal in a clutter environment consisting of other biphase-modulated signals. Analytic results for a white-Gaussian model and for a non-linear capture model are compared with simulation results obtained from an IBM 7094 computer. The white-Gaussian model is in general agreement with the simulation results for equal power clutter signals; the capture model and the simulator yield similar results when a dominant clutter source is present.

Design of an Automatic Telephone Intercept Switch *by G. F. Abbott, R. L. Bence, J. A. Ceonzo, and J. M. Regan, p. 274.* A system has been designed to automatically perform the functions of intercepting misdirected telephone calls and providing correct dialing information. This paper concentrates on the design of the switching unit of the system. The switch

is a space-division, wired-logic controlled device using dry-reed relays as crosspoints. It is organized so that separate networks perform the functions of concentrating incoming lines and selecting operator positions for identification of the number the customer thinks he called. While the presently installed system is not completely automatic, provision is made for incorporation of automatic identification of the "called number" when the necessary telephone central office features become available. Although the system was built for a particular telephone installation, modular construction makes it readily adaptable to installations with a variety of requirements. The switching networks can handle a maximum of 200 incoming intercept trunks, 64 automatic audio response trunks, 22 called-number identifying operators, and 14 special intercept operators.

Filter Performance in Integrated Switching and Multiplexing *by K. M. Roehr, P. M. Thrasher, and D. J. McAuliffe, Jr., p. 282.* To achieve the advantages of a new technique (ISAM) for integrating the functions of time-division switching and frequency-division multiplexing, it is necessary to design filters that are somewhat different from those used in conventional switching and multiplexing systems. This paper analyzes the performance of ISAM filters. Since in the new technique signals are resonantly transferred between band-pass filters, the theory of resonant transfer for this general case is developed. The conditions for obtaining resonant transfer between ideal filters are determined and then the effects of using nonideal filters are investigated. An example is given showing the synthesis of a set of filters designed to meet ISAM requirements.

On Definitions of a Burst *by R. T. Chien and D. T. Tang, p. 292.*

A Technique for Determining and Coding Subclasses in Pattern Recognition Problems *by R. L. Mattson and J. E. Dammann, p. 294.* The problem of organizing and partitioning large amounts of data into classes such that all data in one class will have similar properties is well known in pattern recognition research. The first step in the process, a cluster finding technique, involves grouping a large amount of data into clusters which must be detected and encoded so that automatic pattern recognition can take place. This paper describes a method for detecting and coding clusters. The principal advantages of this technique are that clusters need not be known *a priori* and no matrix inversion is required.

Thermal Problems of the Injection Laser *by R. W. Keyes, p. 303.* Heat is produced during the operation of an injection laser. The thermal conduction problems associated with the flow of the heat away from the junction region have been solved and the temperature increase of the junction has been calculated for several simple model cases. The results have been applied to the calculation of thermal limitations on the performance of gallium arsenide lasers.

Properties of GaAs Diodes with *P*-*P*^{0}-*N* Structures *by K. Weiser, p. 315.* The electrical and electroluminescent properties of GaAs diodes with *P*-*P*^{0}-*N* structure are discussed with special emphasis on their negative resistance characteristics. A description is given of the fabrication of diodes, consisting of a central, manganese-doped, high-resistivity layer (the P^0 region) between low-resistivity *P*- and *N*-layers. The theory of Dumke for the origin of the negative resistance characteristics is shown to give a good account of their static characteristics. Extension of the theory to transient characteristics (i.e., response to voltage pulses in excess of the breakdown voltage) predicts faster switching speeds than have been observed experimentally; nevertheless, diodes fabricated by one technique switch within a few nanoseconds at room temperature with overvoltages of only a few volts.

Vapor-Phase Polishing of Silicon with H_2-HBr Gas Mixtures *by L. V. Gregor, P. Balk, and F. J. Campagna, p. 327.*

Two-Dimensional Laser Deflection Using Fourier Optics *by H. J. Zweig, p. 333.*

Fatigue Strength of Case Hardened Steel Specimens Containing Through-The-Case Cracks *by W. D. Kehr, p. 336.*

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A Hard-Sphere Model to Simulate Alloy Thin Films *by A. S. Nowick and S. R. Mader, p. 358.* A model is developed for the simulation of alloy thin films by forming a layer consisting of spheres of two different sizes mixed randomly in any desired proportion. Included in the model is the possibility for vibration to simulate low-temperature annealing, as well as the use of a "substrate" containing periodic grooves to simulate epitaxial growth. Optical (Fraunhofer) diffraction patterns are taken from photographs of the model for comparison with the structural features observed directly. The model serves to show strikingly the role of the size factor in determining film structures. In particular, it shows that for size differences near 25% amorphous structures are obtained over a wide range of compositions. It also shows that such amorphous structures are essentially unchanged by vibration "annealing." On the periodically grooved substrate, the existence of an "epitaxial" deposition rate is demonstrated. These and other features of the model are compared with experience concerning evaporated thin films and found to be in excellent qualitative agreement.

Observations of "Clean" Surfaces of Si, Ge, and GaAs by Low-Energy Electron Diffraction *by F. Jona, p. 375.* The {100}, {110} and {111} surfaces of silicon, germanium and gallium arsenide, cleaned in ultra-high vacuum by heat-treatments alone or by ion-bombardments followed by anneals, were studied with the display-type low-energy

electron diffraction technique. Most surface structures reported in the literature by others could be reproduced, namely, Si(111)7, Ge(111)8, GaAs(111)2, and GaAs(100)1. Some, however, could not, namely, Si(111)5 and Ge(111)12. Two unreported structures were found to exist, even simultaneously, on the GaAs{100} surface and six different structures were detected on Si{110} surfaces after annealing treatments at different temperatures. The significance of a "clean" state of semiconductor surfaces, as identified by the observation of low-energy electron diffraction patterns, is discussed.

Simulation of the Catalytic Cracking Process for Styrene Production *by B. Davidson and M. J. Shah, p. 388.* A mathematical model is presented for simulating the steady-state catalytic dehydrogenation of ethylbenzene to styrene and other associated side reactions. The various differential equations describing the material and energy balances were integrated using a fourth-order Runge-Kutta method on an IBM 7090. Several runs on the computer were made to study the effect of change in feed rates, feed-to-steam ratio, and inlet temperature and pressure, on styrene yield. It is shown how, with the computer results, a profit equation for a particular plant may be derived for possible use in on-line optimization and control.

Junction Heating of GaAs Injection Lasers During Continuous Operation *by M. H. Pilkuhn and H. S. Rupprecht, p. 400.* The rise of the junction temperature during continuous operation of an injection laser has been measured as a function of current and is discussed for different cases. The dependence of the emitted light power on current is computed from the thermal data and compared with the experiment. The threshold current and the differential quantum efficiency for continuous operation are discussed.

Solution of the Equation for Wave Propagation in Layered Slabs with Complex Dielectric Constants *by J. W. Cooley and F. Stern, p. 405.* A numerical procedure for solving the eigenvalue equation $u'' = [V(x) - E\,]u$, where $V(x)$ is complex, is described. The number of eigenvalues, and their approximate location, can be determined by contour integration in the complex trial eigenvalue plane. Some general features of the solutions, and an example, are given.

The Chain Magnetic Memory Element *by J. C. Sagnis, Jr., P. E. Stuckert, and R. L. Ward, p. 412.*

Digital Pneumatic Logic Using Coded Tapes *by W. F. Voit, Jr., p. 418.*

The Effective Carrier Ionization Rate in a *p-n* Junction at Avalanche Breakdown *by D. P. Kennedy and R. R. O'Brien, p. 422.*

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Solution of the Partial Differential Equations Describing Photodecomposition in a Light-absorbing Matrix having Light-absorbing Photoproducts *by C. E. Herrick, Jr., p. 2.* A solution has been obtained for the system of partial differential equations describing the photolysis of an arbitrary number of light-sensitive materials contained in a semirigid, nonscattering, actinic light-absorbing matrix. Each photoreactant may produce stable, actinic light-absorbing products. The solutions reduce to known closed form expressions for the simplest cases.

Calculations of Impurity Atom Diffusion Through a Narrow Diffusion Mask Opening *by D. P. Kennedy and P. C. Murley, p. 6.* Relaxation methods have been used to solve a mixed boundary value problem arising in the fabrication of junction transistors: impurity atom diffusion through a narrow diffusion mask opening. This particular problem is encountered in the fabrication of very narrow diffused *p-n* junctions. It is shown that the depth of a very narrow junction cannot always be determined from an elementary one-dimensional analysis of this diffusion process. If the width of a diffusion mask opening is less than two impurity atom diffusion lengths, the junction depth becomes geometry dependent. Normalized graphs are presented to illustrate the impurity atom distribution resulting from this particular geometric configuration.

Design Technique for High-Efficiency Frequency Doublers Based on the Manley and Rowe Energy Relations *by E. M. Philipp-Rutz, p. 13.* This paper describes a design technique for high-efficiency microwave frequency doublers using a varactor diode. In this technique design parameters that can be measured in microwave circuits are derived from the Manley and Rowe energy relations in nonlinear reactances. These design parameters are: the characteristic impedances of the transmission lines of the microwave structure, the input and output powers of the frequency doubler, and the distances between the varactor diode and the filters that reject the fundamental frequency and the second harmonic.

The design technique for the microwave frequency doubler enables us to "match" the microwave structure to the varactor diode. Furthermore, the technique makes it possible to convert the maximum real fundamental power in the varactor diode to the second harmonic. The design procedure determines the operating region on the diode characteristic that, for a given diode, yields highest conversion efficiency. Our objective was to evaluate the design parameters of the frequency doubler for the region that gives this efficiency.

Two experimental models of a series type *L*-band frequency doubler were built to verify the design technique. The measured conversion efficiencies of the diodes operated in the doubler were in close agreement with the computed conversion efficiencies. We obtained 5 W output power from the varactor diode at 2.1 Gc/sec with 0.79 efficiency. (These values do not include circuit losses.)

Computation of Ion Trajectories in the Monopole Mass Spectrometer by Numerical Integration of Mathieu's Equation *by R. F. Lever, p. 26.* A high speed digital computer used with an off-line curve plotter enabled ion trajectories to be readily obtained in terms of the initial conditions and the parameters appearing in the differential equation of motion (Mathieu's equation). A study of these trajectories has led to the conclusion that ions should not be injected parallel to the axis of the instrument, as is done at present, but through the axis and at an angle to it. A simple empirical expression enables the variation of position of ion focus with mass and operating parameters to be predicted.

On the Design and Performance of a Small 60-nsec Destructive Readout Magnetic Film Memory *by W. Anacker, G. F. Bland, P. Pleshko, and P. E. Stuckert, p. 41.* The design of a small very-high-speed magnetic film memory using existing components is summarized. The memory has a capacity of 32 words and 36 bits per word, operates in a destructive-readout mode, and has a cycle time of 60 nsec and an access time of 32 nsec. The storage medium is a continuous sheet of NiFe film. The operational characteristics of the film and the properties of the strip line array are given, with worst case pulse conditions applying to both. The design and operation of the electronic circuitry are also described. A model of the memory, populated with three word-driver circuits and three regeneration-loop circuits for reading, rewriting, and writing, has been built and operated successfully. The paper concludes with oscillograms of waveforms which were obtained in closed regeneration-loop operation with that model.

On Measures of Logic Performance: Logic Quantum, Factor, and Figure of Merit *by L. J. Giacoletto, p. 51.* A basic logic operation is considered of transferring a logic decision from one point to another point. A certain energy level, W_L, corresponding to decision threshold and a time delay, T_L, are encountered in the transfer process. The product, $W_L T_L$, is a logic quantum, H_L. If the logic transfer takes place through an intermediate device, a logic factor, F_L, can be introduced to describe the reduction in logic quanta that the device can produce under optimum conditions. Optimization is carried out, as for instance with ideal transformers, to "match" the logic source to the device and the device to the logic detector. The condition $F_L = 1$ marks a boundary between a useful and a useless device, and a logic figure of merit, T_{FM}, in units of time corresponds to the fastest source-detector combination such that $F_L = 1$. Logic performance is considered in some detail for a particular linear model of a device. Nonlinear devices and relay devices are considered in less detail, although some numerical calculations are given for a current-switch, two-transistor computer device. The logic figure of merit represents a unique measure of high-speed logic performance and is

therefore valuable in comparing devices including associated circuitry on a common basis.

Some Experiments in Spoken Word Recognition *by J. H. King, Jr. and C. J. Tunis, p. 65.* This paper describes some experimental work in the recognition of limited-size, but arbitrary, vocabularies of spoken words. The equipment consists of a filter-bank voice-spectrum analyzer providing real-time input of measurement data to an IBM 1620-II digital computer system. The computer implements various transformations on the input data and also implements various linear decision functions which are designed by means of adaptive algorithms. Recognition experiments have investigated the recognition capability of this system on arbitrary vocabularies of up to 30 words. Several normalizing transformations on the primary measurements were investigated.

An Experiment in Cluster Detection *by J. E. Dammann, p. 80.*

The Dispersion Locked Memory Mode for Magnetic Films *by H. J. Kump, H. G. Hottenrott, B. I. Bertelsen, and P. T. Chang, p. 89.* In the usual thin film magnetic memory, that which utilizes the two stable easy direction magnetization states for storage, inverted films ($H_c > H_k$) are often used to reduce disturb sensitivity. In general, inverted films exhibit a high angular dispersion and an open hard direction hysteresis loop with considerable remanence. Middelhoek has attributed this high remanence to the large number of Néel walls formed after the application of a hard direction field exceeding the anisotropy field. The stable state resulting from this "dispersion locking" finds utility as a storage state and is the subject treated here. This paper describes an orthogonal storage mode which could form the basis for a word-organized high-speed memory using unipolar drivers. Test programs and the results obtained therefrom are illustrated to show the useful operating range in a typical film. The total absence of "creep" and the unipolar digit current input to the device are seen to be features of this dispersion locked mode.

Dynamic Thermal Response and Voltage Feedback in Junction Transistors *by F. A. Reid, p. 95.*

Conditions for Termination of the Method of Steepest Descent after a Finite Number of Iterations *by W. E. Langlois, p. 98.*

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Formation of Built-in Light-emitting Junctions in Solution-grown GaP Containing Shallow Donors and Acceptors *by L. M. Foster, T. S. Plaskett, and J. E. Scardefield, p. 114.* The growth of GaP from a gallium-rich solution is described and the morphology and dendritic growth habit of the crystals are discussed. By control of growth conditions it was possible to produce built-in junctions in crystals doped with the shallow donors, S, Se, or Te, and the shallow acceptor, Zn. Green junction electroluminescence of higher efficiency than has been reported heretofore was observed from these structures. The effective segregation coefficients for the above impurities in GaP were determined by radiochemical techniques. On the basis of differences existing between these coefficients for the donor and acceptor dopants, and with the assumption of a two-step growth process, a mechanism for the formation of the junctions during precipitation of the crystals from solution is set forth.

Green Luminescence from Solution-grown Junctions in GaP Containing Shallow Donors and Acceptors *by M. H. Pilkuhn and L. M. Foster, p. 122.* Gallium phosphide diodes doped with shallow donors and acceptors that partially compensate one another in both the *n*- and *p*-regions give rise to bright green emission. This green emission is more efficient at room temperature than the so-called "*A*-line" emission commonly observed in lightly doped diodes. The peak energy of the green emission varies with the donor binding energy, and the emission is interpreted as a radiative donor-acceptor or a donor-valence band transition. Its intensity-voltage dependence and its current-voltage dependence are discussed for room temperature conditions. At 77K, large shifts in peak energy were observed to accompany changes in applied voltage. Data concerning this peak shift, the intensity-voltage dependence, and the linewidth-voltage dependence are presented and discussed. Time effects and the temperature dependence of the quantum efficiency are also examined.

Effects of a Keeper on Thin Film Magnetic Bits *by C. G. Ravi and G. G. Koerber, p. 130.* When Permalloy films are used for computer storage, a magnetic keeper can improve performance by reducing the following undesirable conditions: stray fields from adjacent lines and from adjacent bits; the effect of current spreading in the ground plane; and trapped flux in the ground plane which opposes switching in the absence of a low reluctance path outside the bit. Theoretical analysis and experimental verification of these important keeper functions are presented in this paper. Through the use of high-frequency pulse techniques, effects of both metallic and non-metallic keepers, at distances from the ground plane ranging from 5 to 30 mils, have been determined. By defining efficiency as the percentage reduction in the average of four worst-case effects, the efficiency factor of a metallic keeper is shown to be 56 and that of a non-metallic keeper, 73. It is suggested that better efficiency is due more to lower electrical conductivity than to any intrinsic magnetic properties.

PERT as an Aid to Logic Design *by T. I. Kirkpatrick and N. R. Clark, p. 135.* A new application is presented for PERT, the well-known statistical project-scheduling method. Using PERT, the logic designer could circumvent usually unrealistic worst-case criteria. He substitutes a formalized statistical method which determines (1) expected or most probable delays, (2) critical timing paths, (3) timing slack allowable

between various inputs, and (4) probability of achieving an output by a certain time. From these data the designer can make a meaningful judgment regarding the reliability of his system. Significantly, he may achieve high reliability without being forced to resort to worst-case design.

Design of a Printed Card Capacitor Read-Only Store *by J. W. Haskell, p. 142.* The Printed Card Capacitor Read-Only Store system is introduced as one of three Read-Only Store (ROS) technologies presently employed in the IBM System/360 computers. A detailed description is given of the elementary storage structure—a capacitor matrix with a novel arrangement for rapidly and economically changing the matrix configuration. The changeable element is an etched or printed Mylar card, prepared with standard IBM card-punch equipment. The assembly of storage structures into a compact 4032-word, 60-bit module is described. Considerations involved in the selection of matrix parameters are reviewed and a theoretical analysis of matrix performance is presented. It is shown that some of the limitations associated with a linear matrix are minimized by an incomplete integration of the matrix output. The impact on over-all ROS performance of factors external to the capacitor matrix is considered. These factors include the effects of a noisy drive system and the asymmetrical character of the matrix relative to the access circuitry. Computed and observed results are compared for typical System/360, Model 30 ROS operation. The actual matrix response amplitude is observed to be greater than the computed value due to the level of system background noise; however, computed and observed waveforms are otherwise in good agreement.

A Practical Class of Polynomial Codes *by W. F. Rogers, p. 158.* Error detecting polynomial codes are usually formed by defining a correspondence between data bits and coefficients of the representative polynomial. These codes are easily implemented in hardware using shift registers; however, implementation in character-oriented processors may be too time consuming. A new class of polynomial codes is described for which a correspondence between n-bit data characters and polynomial coefficients is defined. Two particular types of these "character polynomial codes" are discussed; these may be easily implemented with hardware or with processor character manipulations. The burst error detecting ability of these two types of codes is shown to be the same as for the common "bit polynomial codes."

Stimulated Emission Observed from an Organic Dye, Chloro-aluminum Phthalocyanine *by P. P. Sorokin and J. R. Lankard, p. 162.*

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Analysis and Synthesis Procedures for Geneva Mechanism Design *by C. E. Hasty and J. F. Potts, p. 186.* This paper contains general analytical results which can be applied to high-speed Geneva design. The results are derived from classical mechanics theory and provide explicit relationships between the performance parameters (those parameters such as contact stress, maximum load, etc., which can have a significant effect on the mechanism performance) and the design variables which specify a Geneva mechanism (number of slots, wheel diameter, pin diameter, etc.). In the past, the complexity of the mathematical formulation of this problem has precluded synthesis of the Geneva wheel proportions. Using these results, however, it is now possible to synthesize the wheel configuration directly, instead of by a repeated trial and error analysis. Two examples are given demonstrating the analysis and synthesis techniques.

Separation of the Linear and Parabolic Terms in the Steam Oxidation of Silicon *by W. A. Pliskin, p. 198.* Using accurate film thickness measurements, it was found possible to separate linear and parabolic terms in the steam oxidation of silicon, and thus obtain much more precise expressions for the thermal oxidation under different conditions. The combined linear-parabolic relation was found to be applicable to various crystallographic orientations. The pure parabolic "constant" obtained from this relation was the same for different crystal orientations, but the linear term in the relation was found to be very surface sensitive. By these techniques, more accurate parabolic rate "constants" can be obtained and the linearity of the $\log k$ vs $1/T$ plot can be extended to much lower temperatures. The activation energy of the parabolic term for steam oxidation was found to be only 16 kcal/mole. The effect of neglecting the linear term in various methods of computing the parabolic rate is discussed.

Tensor Analysis of Spatial Mechanisms *by C. Y. Ho, p. 207.* The position analysis of a general four-bar spatial mechanism is developed using tensor notation and operations. To exemplify the convenience of tensors in kinematic analysis the solution is obtained for a mechanism containing two revolute pairs of links and two spherical pairs.

Avalanche Breakdown Calculations for a Planar *p-n* Junction *by D. P. Kennedy and R. R. O'Brien, p. 213.* A mathematical analysis is presented on the avalanche breakdown voltage of a planar *p-n* junction. This analysis takes into consideration junction curvature, as encountered near a diffusion mask edge. Three different impurity atom profiles are considered: abrupt, linearly graded, and diffused. For an asymmetrical abrupt structure, it is shown that regions of junction curvature exhibit either an increase or a decrease in avalanche breakdown voltage. It is also shown that similar regions in a linearly graded junction exhibit a combination of these abrupt junction mechanisms; thereby, their breakdown voltage is little influenced by junction curvature. In addition, the diffused planar junction can be designed to exhibit nearly the same breakdown voltage as a corresponding mesa structure, or, instead, it can be designed to exhibit a substantially lower avalanche breakdown voltage.

Stability of Flexible Tapes in Parallel Flow *by G. T. Czaykowski, I. G. Tadjbakhsh, and Y.-O. Tu, p. 220.* A stability analysis by the method of normal modes is carried out for a plane Poiseuille flow in a channel with a free-flying elastic tape in midstream. The effects of transverse and rotary inertia and flexural rigidity of the tape on the stability criteria are investigated. An increase of transverse inertia due to heavier tapes tends to decrease the critical Reynold's number while the addition of flexural rigidity improves the stability criteria by increasing the critical Reynold's number.

Intensity Noise in Multimode GaAs Laser Emission *by A. W. Smith and J. A. Armstrong, p. 225.* As presently manufactured most GaAs lasers have several lasing modes when the injection current is more than 25% above threshold. This paper describes the noise properties of three groups of multimode lasers operating cw at 10K, classified on the basis of their sub-threshold spectra. Two main types of intensity noise have been found: (1) low frequency nonstationary noise which occurs when a weak mode is lasing in competition with a strong mode, and (2) broadband stationary noise which occurs when two modes are about equal in intensity. The first type of noise is believed to arise from heat transfer processes in the diodes and dewar, while the second is probably the partition noise which must occur when a photon can be stimulated into one of a number of lasing modes. An important result of these experiments is that the total noise for all modes is very small, being comparable to that for a single mode with the same total power.

A Theoretical Analysis of Saturation Magnetic Recording *by D. E. Speliotis and J. R. Morrison, p. 233.* A theoretical analysis of the saturation magnetic recording process is presented. The approach is based on the complete characterization of an isolated magnetization transition on the recording surface. The effects of the writing process, demagnetization, recording surface thickness, transducer-to-medium spacing, and readback transducer resolution are considered in calculating the exact pulse shape read back from such an isolated magnetization transition. The theory predicts the significance of each individual parameter that affects the pulse amplitude and resolution of digital recording systems. The theoretical predictions are compared with experimental results measured over a wide range of recording surface properties, and the agreement is excellent. The theory is also in excellent agreement with correlations between magnetic and recording properties that heretofore have been established by experiment alone.

Some New Methods for Digital Encoding of Voice Signals and for Voice Code Translation *by G. Knauft, H. Lamparter, and W. G. Spruth, p. 244.* Recently developed techniques are described for improving the speech quality of voice signals that are first digitally encoded, placed in random access storage, and on demand are then translated into normal speech in an audio response unit under the control of a host processor. The development is an extension and modification of the channel vocoder principle. Speech quality is enhanced by hardware and software features for treatment of unvoiced components of the coded speech signal in particular by separating harmonics from the excitation function digital signal before smoothing. A new program of bit selection is used to assure that the aggregation function digital signal carries maximum information. In addition, an efficient method of storage assignment is shown for the excitation function and the aggregate function registers in the voice code translator.

Thermostrictive Recording on Permalloy Films *by H. J. Kump and P. T. Chang, p. 255.* Where the magnetostrictive coefficient is of the order of 10^{-6} or greater, recording may be accomplished on uniaxial Permalloy films by the application of a local stress in coincidence with a biasing field. Here, the stress is introduced into the film as a result of a temperature gradient produced by an incident laser or electron beam.

The mechanism of recording is studied and a model developed in agreement with the mechanism. Several modes of recording are discussed, with the advantages and disadvantages of each. Extrapolating the model to a large capacity memory of 10^7 bits per square inch with 8 micron diameter spots on a Permalloy film having a magnetostrictive coefficient of 10^{-5}, a 20°C temperature rise will be experienced with 2×10^{-10} joules of energy in the beam. The beam power required is 10^{-3} watts at 10% efficiency and a one megacycle information rate.

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Diagnosis of Automata Failures: A Calculus and a Method *by J. P. Roth, p. 278.* The problem considered is the diagnosis of failures of automata, specifically, failures that manifest themselves as logical malfunctions. A review of previous methods and results is first given. A method termed the "calculus of D-cubes" is then introduced, which allows one to describe and compute the behavior of failing acyclic automata, both internally and externally. An algorithm, called the D-algorithm, is then developed which utilizes this calculus to compute tests to detect failures. First a manual method is presented, by means of an example. Thence, the D-algorithm is precisely described by means of a program written in Iverson notation. Finally, it is shown for the acyclic case in which the automation is constructed from AND'S, NAND'S, OR'S and NOR'S that if a test exists, the D-algorithm will compute such a test.

A Numerical Analysis of the Transient Behavior of a Transistor Circuit *by R. K. Brayton, F. G. Gustavson, and W. Liniger, p. 292.* This paper describes some difficulties encountered in the numerical solution of nonlinear circuit equations. A particular transistor circuit is analyzed to illustrate the nature of the difficulties and how they may be resolved. In this circuit it is possible, without sacrificing

accuracy of the physical model, to eliminate unimportant stray parameters whose presence destroys the efficiency of most integration routines. A method based on a potential function is used for deriving the circuit equations and it is shown how these equations can be systematically reduced upon removing the stray parameters. Application of such techniques to the circuit considered reduced the calculation time (on an IBM 7094) from 30 minutes to 7 seconds.

Properties of a Free, Steadily Travelling Electrical Domain in GaAs *by J. B. Gunn, p. 300.* Experiments are described on the travelling domains of high electric field which can exist in *n*-type GaAs. A brief discussion of the appearance of stationary domains near the cathode and of the nucleation and transient behaviour of travelling domains is given, but the main topic is the steady-state behaviour of travelling domains. Measurements are reported on the dependence of domain velocity, and of the voltage drop across the domain, on the field E_∞ existing outside the domain. It is found that the velocity increases with E_∞, but the voltage decreases. The resulting negative resistance is seen to have important consequences for the stability of the domain in real specimens.

Effect of Domain and Circuit Properties on Oscillations in GaAs *by J. B. Gunn, p. 310.* A discussion is given of the complications obtaining when a bar of GaAs, generating microwave oscillations, is allowed to interact with an external circuit. Three very different modes of operation can be expected, each corresponding to a mechanism of extinction of the travelling domains of electric field that cause the current modulation. It is seen that the domains may be extinguished (1) when they reach the end of the bar, (2) when the voltage drops too low for the stability of a domain, or (3) when it rises too high. In the last two circumstances, the external circuit plays an important role. Conditions for the existence of the various modes are deduced, and their properties are studied experimentally.

Resonant Excitation of Magnetostrictive Driven Print Wires for High-Speed Printing *by M. Preisinger, p. 321.* A developmental resonant wire printing device utilizing ultrasonic vibration is described and results given on some preliminary work on the resonant excitation of magnetostrictive print wires. This paper discusses the characteristics of the magnetostrictive material, the transducer design and some special methods of measuring small, rapid mechanical motion. In the present test setup of the printing device, impact rates up to 1400/sec were obtained.

A High-Speed Read Only Store Using Thick Magnetic Films *by R. E. Matick, P. Pleshko, C. Sie, and L. M. Terman, p. 333.* This paper describes a high-speed, magnetic film, read only store of about 300K bits. The device and its implementation into a system have many unique advantages, including loose magnetic tolerances, minimal delay in the cell, linear drive-sense coupling, and ease of information change. The basic device consists of a thick, anisotropic magnetic film sandwiched between the conductors of a strip transmission line. The cell utilizes the coupling between parallel word and sense line sections obtainable through the hard axis characteristics of an anisotropic permalloy film to store a binary ONE state. For a ZERO the coupling is inhibited by saturating the film with a small permanent magnet. Switching of the film can be described qualitatively, and to a large extent quantitatively, by a quasistatic analysis. A dynamic analysis describes the behavior of the film more completely and aids in optimization of some film parameters.

The ROS system is designed in four planes of 256 words by 288 bits each. A single array plane was built and tested with a cross-section of drive and sense circuits. Because of the linear drive-sense relationship, the array can preferably be driven with a low current directly from a logic stage. The worst-case access time, including one level of decode, was measured to be 19 ns; the corresponding cycle time was 45 ns.

Localized-Field Permanent Magnet Array for the Thick-Film Read Only Store *by C. Johnson, Jr. and R. C. Turnbull, p. 343.*

Dynamic Laser Wavelength Selection *by M. A. Habegger, T. J. Harris, and E. Max, p. 346.* This paper describes the dynamic selection of the emission wavelengths of a laser by insertion of a dispersive tunable electro-optic *Q*-spoiler within the laser cavity. Five different oscillation wavelengths of an argon ion laser have been individually selected by varying the voltage on the KD*P electro-optic crystals in the *Q*-spoiler.

Domain Wall Velocities in Thin Magnetic Films *by S. Middelhoek, p. 351.*

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Design of Monolithic Circuit Chips *by O. Bilous, I. Feinberg, and J. L. Langdon, p. 370.* The influence of semiconductor chip design on the logic partitioning of a computer is discussed and some design rules are given. A chip size of 60 × 60 mils with 24 terminals and 168 components was shown to be optimum. RF-sputtered quartz insulation was used for multilevel wiring and a hermetic seal. Using a master chip technique, a 9-part-number logic set was successfully fabricated. Propagation delays for the circuits were 2.5 to 3 nsec.

Theory of Domain-Wall Structure in Multiple Magnetic Films *by J. C. Slonczewski, p. 377.* This paper derives analytically a two-dimensional wall-structure applying to the case of two identical magnetic films separated by a non-magnetic film. It applies also to a variety of other multilayer problems. The calculation is based on the usual micro-magnetic principle of energy minimization and all approximations are justified. The wall-structure is found to

consist of two "flank" regions, whose shape is governed by anisotropy and stray-field coupling between films, arranged symmetrically about a central "kernel" region whose shape is governed by anisotropy and exchange. In the widely applicable limit of negligible exchange the theory reduces to one given earlier [*J. Appl. Phys.* **37**, 1268 (1966)]. Also included in the discussion are effects of quasi-walls and film-to-film exchange interactions. Existing experimental data on wall-shape confirm the shape of the kernel but are not of sufficient precision to test the shape of the flanks. Existing data for permalloy suggest that perpendicular anisotropy may play a significant role in reducing multiple-film wall energy and thickness.

On Multi-Head Finite Automata *by A. L. Rosenberg, p. 388.* Let M_n be the class of languages defined by n-head finite automata. The Boolean and Kleene closure properties of M_n are investigated, and a relationship between M_n and the class of sets of n-tuples of tapes defined by n-tape finite automata is established. It is shown that the classes M_i form a hierarchy; and that, moreover, for all n, there is a context-free language (CFL) in $M_{n+1} - M_n$. It is further shown that there is a CFL which is in no M_n for any integer n. Finally, several decision properties of the multi-head languages are established.

The Quantum Mechanical Extension of the Boltzmann Equation *by P. J. Price, p. 395.* It is shown that the method of Kohn and Luttinger may be applied to obtain a generalized Boltzmann equation, for electrons in a solid, when the driving field has nonzero wavevector as well as frequency. By means of this equation, the behavior of the electrons in response to the field may be followed from the quasi-classical limit at small rates of change to the quantal limit at large rates of change.

End-Pumped Stimulated Emission from a Thiacarbocyanine Dye *by P. P. Sorokin, W. H. Culver, E. C. Hammond, and J. R. Lankard, p. 401.*

The Kantorovich Theorem and Two-Point Boundary Value Problems *by S. M. Roberts and J. S. Shipman, p. 402.*

Digital Simulation of Image-Forming Systems *by D. P. Paris, p. 407.*

Design of a Moiré Fringe Torque Transducer *by T. D. Abbott, p. 412.*

Influence of Non-ideal Filters on the Transmission Characteristics of Resonant Transfer Switching Systems *by K. M. Roehr, p. 416.*

Surface Attack in Chromium-Iron Alloys *by W. D. Kehr and H. E. Seese, p. 420.*

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Gallium Arsenide Planar Technology *by W. von Münch, p. 438.* Some of the main problems of the gallium arsenide planar technology are discussed. The most suitable starting material used has been obtained by vapor growth. Methods of zinc and tin diffusion have been studied in connection with masking by pyrolytic SiO_2/P_2O_5 layers. An alternative technique using doped silicon dioxide for the production of planar devices has been developed. The latter method features complete surface protection and easy control of the impurity concentration. The application of both methods to the production of *npn, pnp,* and four-layer devices is described. Using an epitaxial etch-refill technique it is possible to obtain electrically isolated devices on a common semi-insulating GaAs substrate.

Dislocation-Induced Deviation of Phosphorus-Diffusion Profiles in Silicon *by M. L. Joshi and S. Dash, p. 446.* Deviation of phosphorus-impurity profiles in silicon from ideal ones under the diffusion condition of high surface concentrations is well known. Diffusion of high concentrations of phosphorus is also known to cause generation of dislocations with edge character in silicon wafer surfaces. A major cause of the deviation of the phosphorus profile is shown to be solute accumulation at these dislocations. The dislocation-precipitated profile is calculated for the ideal complementary error-function diffusion profile of phosphorus with 10^{21} atoms/cm^3 of surface concentration, using Ham's model of stress-assisted precipitation on dislocations. The results are shown to account for most of the major features of the experimental diffusion profiles.

The Integrated Vocoder and its Application in Computer Systems *by E. H. Rothauser, p. 455.* This paper reviews the conceptual features and the applications of the integrated vocoder. In a comparison with the structural properties of the channel vocoder and other experimental types, the integrated vocoder is shown to be a technically simple solution to the well-known problems of pitch description and vocoder signal transmission. The design reduces the complexity of the over-all speech processing equipment and features a saving in device hardware. The potential of this vocoder design for time division multiplex transmission systems is discussed and an application of the new vocoder concept is shown for computer input-output equipment.

New Methods for De Haas-Shubnikov Measurements *by R. D. Brown III, p. 462.* Improved techniques and instrumentation for observing the de Haas-Shubnikov (dHS) effect are described and preliminary results of their application to measurements on bismuth are presented. The two main features of the method are: first, the monotonic H^2 term in the magnetoresistance is subtracted out, allowing increased amplification of the oscillatory part, and therefore increased sensitivity in detecting the periods; second, the magnetic field is swept such that $1/H$ varies linearly in time, producing dHS

oscillations sinusoidal in time, making it possible to use real-time differentiation and filtering to separate interfering periods. The method thus provides a large amount of data reduction prior to recording, permits direct measurement and averaging of the periods from the recorded data, and allows a more accurate and unambiguous interpretation of the data. Much of the instrumentation described ($1/H$ sweep, filter, differentiator) has been built around commercially available operational amplifiers.

A Partial Error Analysis for the Solution of Differential Equations in Simulation: A Look at Fowler's z-Transform Root-Locus Method *by J. W. Daniel, p. 472.* A partial analysis is made of the types of error of Fowler's method, which uses the z-transform procedure for digital simulation of complex systems.

In-situ Measurements of Magnetic Properties in Vacuum-Deposited Permalloy Films *by K. Y. Ahn, p. 477.* The quasi-static magnetic properties of vacuum-deposited Permalloy films of zero-magnetostrictive composition are examined *in situ* in an evaporator equipped with a laser-operated Kerr magneto-optic hysteresigraph. The coercive force, which depends strongly upon the film thickness, is large ($H_c > 20$ Oe) when the hysteresis loop is first observable with a thickness of ~ 50 Å for low substrate temperatures ($T < 50$°C) and ~ 100 Å for high substrate temperatures ($T > 100$°C). There are two peaks of coercivity, at ~ 400 Å and ~ 1000 Å; the two are thought to be related, respectively, to the transitions from the Néel to the cross-tie walls, and from the cross-tie to the Bloch walls. Two distinct components of the uniaxial anisotropy field are identified, both of which are characteristic of fabrication parameters: K_1, which is difficult to re-orient once the anisotropy is induced; and K_2, which is readily re-oriented (with time constant less than 10 sec) along any angle between the easy and the hard axis. The net anisotropy field and the easy-axis orientation, both of which are affected by the K_2 components, can be calculated for a given set of fabrication parameters. Experimental results agree well with the calculated values. The angular dispersion does not appear to be affected by the amplitude of the orienting field H or the nature of the field (a.c. or d.c.) when $H > H_c$. There is a slight increase in angular dispersion as the K_2 component of the anisotropy rotates from the easy to the hard axis.

Electron Barriers in Al-Al_2O_3-SnTe and Al-Al_2O_3-GeTe Tunnel Junctions *by L. L. Chang, P. J. Stiles, and L. Esaki, p. 484.*

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The IBM System/360 Model 91: Some Remarks on System Development *by M. J. Flynn and P. R. Low, p. 2.*

The IBM System/360 Model 91: Machine Philosophy and Instruction-Handling *by D. W. Anderson, F. J. Sparacio, and R. M. Tomasulo, p. 8.* The System/360 Model 91 central processing unit provides internal computational performance one to two orders of magnitude greater than that of the IBM 7090 Data Processing System through a combination of advancements in machine organization, circuit design, and hardware packaging. The circuits employed will switch at speeds of less than 3 nsec, and the circuit environment is such that delay is approximately 5 nsec per circuit level. Organizationally, primary emphasis is placed on (1) alleviating the disparity between storage time and circuit speed, and (2) the development of high speed floating-point arithmetic algorithms.

This paper deals mainly with item (1) of the organization. A design is described which improves the ratio of storage bandwidth and access time to cycle time through the use of storage interleaving and CPU buffer registers. It is shown that history recording (the retention of complete instruction loops in the CPU) reduces the need to exercise storage, and that sophisticated employment of buffering techniques has reduced the effective access time. The system is organized so that execution hardware is separated from the instruction unit; the resulting smaller, semiautonomous "packages" improve intra-area communication.

An Efficient Algorithm for Exploiting Multiple Arithmetic Units *by R. M. Tomasulo, p. 25.* This paper describes the methods employed in the floating-point area of the System/360 Model 91 to exploit the existence of multiple execution units. Basic to these techniques is a simple common data busing and register tagging scheme which permits simultaneous execution of independent instructions while preserving the essential precedences inherent in the instruction stream. The common data bus improves performance by efficiently utilizing the execution units without requiring specially optimized code. Instead, the hardware, by 'looking ahead' about eight instructions, automatically optimizes the program execution on a local basis.

The application of these techniques is not limited to floating-point arithmetic or System/360 architecture. It may be used in almost any computer having multiple execution units and one or more 'accumulators.' Both of the execution units, as well as the associated storage buffers, multiple accumulators and input/output buses, are extensively checked.

The IBM System/360 Model 91: Floating-Point Execution Unit *by S. F. Anderson, J. G. Earle, R. E. Goldschmidt, and D. M. Powers, p. 34.* The principal requirement for the Model 91 floating-point execution unit was that it be designed to support the instruction-issuing rate of the processor. The chosen solution was to develop separate, instruction-oriented algorithms for the add, multiply, and divide functions. Linked together by the floating-point instruction unit, the multiple execution units provide concurrent instruction execution at the burst rate of one instruction per cycle.

The IBM System/360 Model 91: Storage System *by L. J. Boland, G. D. Granito, A. U. Marcotte, B. U. Messina, and J. W. Smith, p. 54.* This paper discusses the design concepts employed in the development of the IBM System/360 Model 91 storage system. Particular attention is paid to the exploitation of System/360 capabilities in the areas of large storage capacity, concurrent operation, and flexibility, as they apply to the highly overlapped Model 91 system.

An interleaved set of main storage modules is used with the Model 91 to help mask the difference between machine cycle time and storage access time. The set is connected to the central processor, peripheral storage control element and maintenance console by three time shared busses—one for addresses, one for data-in, and one for data-out. The main storage control element (MSCE) controls these busses to maximize the storage access rate. To achieve minimum access time, requests are normally sent directly to the storage modules. The proper module is selected by the MSCE, the address gated in, and the storage cycle started. If the module is busy from a previous request, the request is stored in a request stack for a later attempt. If the request is accepted, it is stored in an accept stack. This stack controls the data-out gating of the storage modules, and notifies the CPU of the destination of returning data. It also furnishes module busy information which controls the recycling of rejected requests.

An important feature is the ability of the MSCE to logically sequence store/fetch requests, by interlocking the rejected requests with the current request without any degradation of minimum access time. Additionally, each address sent to the MSCE is compared with the addresses of waiting and in-process requests. This allows serial fetching of two adjacent single words of a double-word storage cycle. Fetches following stores to the same location can be executed without waiting for a fetch storage cycle.

Peripheral storage is provided in the system for both block transfers of data and individual word fetches and stores. All requests to peripheral storage are sent via the peripheral storage control element.

The MSCE is synchronized with the CPU and uses the same machine cycle. Ideally, a request can be honored each machine cycle, but the actual rate is determined by storage module conflicts. The storage system performance is measured in access rate and access time. The MSCE has been simulated to measure the effects of storage speeds, degree of interleaving, and changes in MSCE controls.

Design of a High-Speed Transistor for the ASLT Current Switch *by J. L. Langdon and E. J. Van Derveer, p. 69.* The evolution of a high-speed current switch transistor design is described from initial design considerations through final optimization of horizontal geometry. It was found that a very narrow geometry was desirable, in order to produce the desired low base resistance (~ 40 Ω). Other characteristics of this design include low capacitance, well-controlled emitter forward voltage, and high-frequency cutoff. Compatibility with the SLT form factor assures manufacturability. This transistor when used in ASLT circuits yields circuit delays of 1.8 nsec.

ASLT Circuit Design *by R. F. Sechler, A. R. Strube, and J. R. Turnbull, p. 74.* The full switching-speed potential of high performance transistors is difficult to realize in a current switch configuration because of the instability which exists when many circuits are interconnected in a system. With a phase compensating network in the emitter current source, however, it has been possible to design a stable circuit using 1 Gc/sec transistors. Design techniques and engineering aspects of the circuit which result in a 5-nsec in-the-environment propagation delay are described. Particular attention is given to the dc design, stability analysis, switching performance, evaluation and specification of the circuit.

ASLT: An Extension of Hybrid Miniaturization Techniques *by R. H. F. Lloyd, p. 86.* The hybrid miniaturization technique of applying active and passive components separately to a packaging substrate enables independent customization of components and minimizes stray capacitance between components. Manufacturing advantages result because all components can be pretested, and the critical component joining operation can be performed as a continuous operation. This paper describes IBM's Advanced Solid Logic Technology (ASLT) wherein the capabilities of hybrid circuit technology have been extended to produce a high-speed, high-density digital logic module compatible with automated production. Design considerations and assembly processes are detailed. A development of the power handling capability reviews the various thermal paths within the module.

Review of Wall Creeping in Thin Magnetic Films *by S. Middelhoek and D. Wild, p. 93.* Domain wall creeping in thin magnetic Ni-Fe films has been studied as a function of the film thickness, field pulse amplitude, duration and repetition frequency, and bias fields in the hard direction. The experimental results are reviewed and compared with the three existing theories, which ascribe wall creeping to a) Bloch line motion, b) wall structure changes, and c) changing magnetic charges along the walls, respectively. Based on the first theory, methods are indicated by which a reduction of creep sensitivity of magnetic films might be obtained.

A Rapid Method for Determining Compound Composition of Cement Clinker: Application to Closed Loop Kiln Control *by P. K. Mehta and M. J. Shah, p. 106.* A procedure for determination of phase composition of commercial cement clinker using quantitative x-ray powder diffraction analysis is described. An external standard and comparison of peak heights rather than the peak areas are used for rapid analysis. Several standard curves were prepared using diffraction patterns from known mixtures of previously prepared pure components which exist in cement clinker. For purposes of comparison, both the suggested external standard method and the internal standard method which is generally accepted for quantitative X-ray diffraction analysis were used. It was found that the faster external standard method gives analysis of important clinker constituents with accuracy adequate for quality control in a cement plant. With the use of suggested grinding procedure and an automatic sample changer attachment to standard X-ray diffraction equipment, it is possible to obtain an on-line analysis of clinker in one half hour. This analysis can then be deployed in performiag closed loop control of a cement kiln with a proposed algorithm.

On the Necessity to Examine D-Chains in Diagnostic Test Generation—An Example *by P. R. Schneider, p. 114.*

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Laser-pumped Stimulated Emission from Organic Dyes: Experimental Studies and Analytical Comparisons *by P. P. Sorokin, J. R. Lankard, E. C. Hammond, and V. L. Moruzzi, p. 130.* Stimulated emission spectra of two organic dyes, chloro-aluminum phthalocyanine (CAP) and 3,3'-diethylthiatricarbocyanine iodide (DTTC) are compared. Giant-pulse ruby laser excitation was used in both cases. An end pumping configuration employed with DTTC resulted in narrow beam divergences and high conversion efficiencies. For CAP, the oscillating transition is one which terminates on an excited vibrational level of the ground electronic state. For DTTC, stimulated emission at the lowest concentrations occurs at the peak of the Franck-Condon-shifted fluorescence band but moves to longer wavelengths as the concentration is increased. The transient behavior of the CAP laser, pumped in a transverse geometry, was observed and compared with computer solutions of the rate equations. Polarization measurements of the laser beams were also made. An analysis is given of requirements for achieving optimal pumping by means of flashlamps. [The paper concludes with an addendum reporting recent observations of stimulated emission from dye solutions lasing at wavelengths ranging from blue (4385 Å) to orange (6000 Å)].

Flashlamp Excitation of Organic Dye Lasers: A Short Communication *by P. P. Sorokin and J. R. Lankard, p. 148.*

A 110-Nanosecond Ferrite Core Memory *by G. E. Werner, R. M. Whalen, N. F. Lockhart, and R. C. Flaker, p. 153.* The

design of a large, very-high-speed ferrite memory is described. The memory has a capacity of 8192 words, 72 bits per word, and has a cycle time of 110 nanoseconds and an access time of 67 nanoseconds. The storage devices are miniature ferrite cores, 0.0075 by 0.0123 by 0.0029 inches, and are operated in a two-core-per-bit destructive read-out mode. A planar array geometry with cores resting on a single ground plane is used to control drive line parameters. Device switching speed and bit line recovery are treated as special problems. The design criteria and operational characteristics of the core, and the approach taken on the bit line recovery problem, are also presented.

A Very-High-Speed, Nondestructive-Read Magnetic Film Memory *by G. Kohn, W. Jutzi, T. O. Mohr, and D. Seitzer, p. 162.* A very-high-speed thin magnetic film memory has been designed and built as a cross sectional test model for 140,000 bits. It can be operated in the NDRO mode with a 20-nsec read cycle time and a 30-nsec access time, and it can be read 65 nsec after the beginning of a write operation.

Device and Array Design for a 120-Nanosecond Magnetic Film Main Memory *by E. W. Pugh, V. T. Shahan, and W. T. Siegle, p. 169.* Device and array design considerations are described for a manufacturable 120-nsec cycle magnetic film memory containing 600,000 bits in the basic operating module. Worst-case testing is done in such a way as to provide quantitative values for such effects as adjacent bit-line stray field, ground-plane current spreading, flux trapping in metallic ground planes and strip lines, and magnetic-keeper efficiency. Worst-case output signals exceeding 3.8 mV are achieved with a 8-nsec rise-time word pulse of 510 mA. Bit current is 100 mA.

Direct Digital Processor Control of Stepping Motors *by T. R. Fredriksen, p. 179.* This paper describes the concept for implementing direct computer control of stepping motors. The design approach is based on using the computer to close a minor loop around the motor. The discussion includes both full and partial computer control, and the results show that the closed-loop stepping motor is well suited to such applications.

Digital Simulation Applied to a Photo-Optical System *by R. B. Edwards, D. T. Hodges, Jr., W. D. Hopkins, and D. P. Paris, p. 189.* The validity of the Image Forming Systems Simulator, IMSIM/1, as a means of simulating multiple-stage photo-optical systems has been determined. IMSIM/1 was used to simulate a three-stage system consisting of a microfilm camera (first stage), followed by the photo-optical subsystem of a developmental image storage and retrieval system (second and third stage). Fine line targets were processed through the camera and the storage and retrieval system. Microdensitometer scans of the targets were then processed through the simulator. To compare the output of the real system with the output of the simulator, it was necessary to measure carefully those system and camera data used in the simulator. After this was done, a satisfactory agreement between experimental result and simulator output was achieved.

On the Partial Difference Equations of Mathematical Physics *by R. Courant, K. Friedrichs, and H. Lewy, p. 215.* **Editor's note:** This paper, which originally appeared in *Mathematische Annalen* **100**, 32–74 (1928), is republished by permission of the authors. We are also grateful to the Atomic Energy Commission for permission to republish this translation, which had appeared as AEC Report NYO-7689, and to Phyllis Fox, the translator, who did the work at the AEC Computing Facility at New York University under AEC Contract No. AT(30-1)-1480. Professor Eugene Isaacson had made suggestions on this translation.

Hyperbolic Difference Equations: A Review of the Courant-Friedrichs-Lewy Paper in the Light of Recent Developments *by P. D. Lax, p. 235.* The portion of the Courant-Friedrichs-Lewy paper [*Math. Ann.* **100**, 32 (1928)] that was devoted to hyperbolic difference equations is critically reviewed in terms of its basic contribution to the numerical solution of partial differential equations. Some subsequent developments are then discussed, including recent literature related to the von Neumann condition, some irreversible schemes, generalizations of the energy method, some new difference schemes, and mixed initial boundary value problems.

On Difference Methods for Parabolic Equations and Alternating Direction Implicit Methods for Elliptic Equations *by O. B. Widlund, p. 239.* Some aspects are discussed of the development of the theory of difference approximations to parabolic equations in its relation to the basic development of difference methods for hyperbolic and elliptic equations by Courant, Friedrichs and Lewy, [*Math. Ann.* **100**, 32 (1928)]. The present paper also deals with the related problem of establishing the convergence of alternating direction implicit methods for elliptic problems.

Elliptic Equations *by S. V. Parter, p. 244.* A brief review is given of the literature on numerical methods for elliptic problems as related to the ideas introduced by Courant, Friedrichs and Lewy in the fundamental paper published in *Math. Ann.* **100**, 32 (1928). The discussion shows how the finite-difference methods have subsequently been extended and applied to higher order elliptic problems and how the recent literature has reported methods for solving large algebraic systems. In addition, there is a discussion of the relation between the Dirichlet problem and the problem of the random walk.

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On the Mathematical Theory of the Linearly-Graded *P-N* Junction *by D. P. Kennedy and R. R. O'Brien, p. 252.* This paper presents a numerical analysis of the mechanisms of operation within a linearly-graded *p-n* junction. Considered

in this analysis are three important modes of junction operation: equilibrium, forward bias, and reverse bias in the collector junction. In addition, calculations of electrical space-charge layer capacitance are presented for the forward-biased linearly-graded junction. The conclusions derived are compared, in graphical form, with the results of previous investigations of the linearly-graded junction.

Precipitation of Phosphorus, Arsenic, and Boron in Thin Silicon Foils *by M. L. Joshi and S. Dash, p. 271.* Diffusion of high concentrations of P, B, and As in thin foils of silicon of (111), (110), and (100) orientations is shown to result in extensive precipitation. Observation of the precipitates through a transmission electron microscope has indicated that phosphorus diffusion gives rise to precipitate platelets. Boron precipitates were found to be of various shapes—rod, platelet, and three-dimensional. Matrix contrast observation showed that small coherent platelets of P and B are both of the "vacancy" type—this is in accordance with the smaller size of B and P atoms in the silicon matrix. Contrast studies for arsenic precipitates were inconclusive. Helical dislocations oriented along <220> directions and originating from precipitate regions were observed in the phosphorus-diffused foils; boron precipitates showed no such helices. Boron rods and three-dimensional structures, however, were invariably found to be enveloped by dislocation spirals, with Burgers vector different from the usual $a/2$ <110> type. These dislocation envelopes are thought to be interfacial dislocations. It is concluded that the precipitates are not identifiable as discrete SiP or Si_xB_y phases, since these phases would be expected to cause compression in the matrix because their specific volume is higher than that of silicon.

On the Velocity of a Domain Wall in an Applied Magnetic Field *by W. Palmer and R. A. Willoughby, p. 284.* A numerical study is made of a moving magnetic domain wall. It is assumed that the wall moves with a uniform velocity V under the influence of an applied magnetic field of magnitude H_0. This leads to a boundary value problem on a doubly infinite line. By using a symmetry in the problem, the inherent difficulty of a two-dimensional search on a doubly infinite line is bypassed. For each V the problem is solved as a sequence of initial value problems involving a one-dimensional search. A limiting velocity is determined by means of an eigenvalue analysis. The curve representing the relation between V and H_0 is determined for a particular case.

Characteristics of the Chain Magnetic Film Storage Element *by P. Geldermans, H. O. Leilich, and T. R. Scott, p. 291.* This paper reports results of a detailed performance evaluation of the chain magnetic film storage element. The chains are made from copper strips which have been plated with a Ni-Fe film and are used to carry word current. The bit/sense signals are carried in wires which pass through the holes in the "links" of the chain. The memory element thus formed will operate in a rotational switching mode and can be used for a word-organized memory.

The results indicate both the advantages and the shortcomings of the device. Because of the complete flux closure, comparatively high output signal flux (200 mV-nsec) can be obtained from small, densely packaged devices which require less than 200 mA of word current and less than 100 mA of bit current. The chain shows high magnetic stability and can be operated in both a destructive and a nondestructive mode. The main problem is the difficulty in handling the delicate self-supporting magnetic devices, for testing, packaging, and wiring; this difficulty determines the limit of miniaturization.

Experimental results, including a large-scale reproducibility study, verify theoretical expectations.

Design Considerations for the Chain Magnetic Storage Array *by S. A. Abbas, H. F. Koehler, T. C. Kwei, H. O. Leilich, and R. H. Robinson, p. 302.* A computer storage design using the chain store device as both a DRO and an NDRO storage element is discussed for an array organization of one megabit capacity and 500-nsec cycle time. The bit/sense system and schemes for minimizing the longitudinal fields inside the array during the "write" portion of the cycle are presented.

Noise due to difference in the information states of the device is studied experimentally and through evaluations of computer solutions of simulated bit/sense lines. The word-line characteristic impedance and its dependence on the magnetic behavior of the device during the "read" portion of the cycle and on the sending and receiving end terminations are examined with consideration given to long word lines. Sources of noise and bit-to-bit interaction are discussed and comparisons between calculated and experimental results obtained from a small model of the array are given.

A Computer Model for Global Study of the General Circulation of the Atmosphere *by D. A. Quarles, Jr. and K. Spielberg, p. 312.* A mathematical model is developed for global prediction of large-scale movements and mean properties of the atmosphere from simulated initial weather conditions. A novel feature is the development of the formulation—one of considerably greater complexity than those for previous weather models adapted to machine calculation—in a concise tensor form. The organization of the computational task illustrates how a very complex problem with vast data requirements may be solved on a computer with limited high-speed storage.

A New Current Instability in *N*-type Germanium *by J. C. McGroddy and M. I. Nathan, p. 337.* This paper reports the observation of a new oscillatory phenomenon in n-type Ge at 77K. The effect is a coherent oscillatory component of the current through a bar of n-type Ge with ohmic n^+ contacts initiated when the average electric field in the sample exceeds some threshold value which is in the region where the electron drift velocity is nearly saturated. The frequencies of the oscillations vary from a few hundred MHz to 2.8 GHz. The

effect depends on sample orientation, temperature, and carrier concentration. Some possible mechanisms for this effect are discussed. At somewhat higher fields a second, not necessarily related instability, is also observed.

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A Generalized Legendre-Clebsch Condition for the Singular Cases of Optimal Control *by H. M. Robbins, p. 361.* For certain optimal control problems, some of the extremal trajectories generated by simultaneous solution of the state and adjoint equations may include arcs of a special character, called "singular" arcs. The optimality of singular arcs has been the subject of considerable uncertainty, since the classical criteria are inapplicable or inconclusive. This uncertainty has recently been reduced by the discovery of additional necessary conditions for the optimality of singular arcs. The principal result of this paper is a general statement and proof of these conditions, in the form of a "generalized Legendre-Clebsch condition" which reduces to the classical Legendre-Clebsch condition when applied to nonsingular arcs, and gives additional necessary conditions when applied to singular arcs. Other results include a classification of the possible singular arcs, a useful extension of the conventional optimal-control formalism (by the introduction of "generalized Hamiltonians" and "generalized control transformations"), and some interesting variational formulae.

Rapid Computation of Optimal Trajectories *by K. R. Brown, Jr. and G. W. Johnson, p. 373.* A generalized "indirect" method of solving two-point boundary value problems is discussed in application to the problem of computing optimal trajectories in a vacuum. Improved numerical techniques make the method extremely fast when a good initial estimate of the solution is available, but it also converges, more slowly, from initial estimates that are far from the solution. Transversality conditions are combined with final-value constraints enabling the method to solve directly problems defined by constraints on arbitrary functions of final state.

Section 1 defines the differential equations and initial and terminal conditions for optimal rocket trajectories in a central gravitational field. The differential equations are given a particularly simple form and transversality conditions are formulated analytically for typical orbital injection missions. Section 2 defines efficient numerical procedures for solving the initial value problem of optimal trajectories and so reduces the boundary value problem to a multidimensional zero-finding problem. Section 3 describes the generalized version of Newton's method used to solve this multidimensional zero-finding problem. Section 4 summarizes the results of an IBM 7094 implementation, giving execution times and convergence properties.

Some Results in Two-Point Boundary Value Problems *by S. M. Roberts and J. S. Shipman, p. 383.* Two new results in two-point boundary value problems are presented. The first is a modified method of adjoints which, under certain circumstances, will solve numerically two-point boundary value problems faster than the standard method of adjoints. The second result shows that Friedrichs' solution of the operator equation $P(x) = 0$ is really the modified Newton method. Kantorovich's sufficiency conditions for the convergence of the modified Newton's method are compared with Friedrichs' sufficiency conditions; it appears that, for most applications, the former conditions allow more leeway.

Computer Control of a Paper Machine—an Application of Linear Stochastic Control Theory *by K. J. Åström, p. 389.* This paper describes an attempt to apply linear optimal control theory to computer control of an industrial process. The applicability of the theory is discussed. Particular attention is given to the problem of obtaining a mathematical model of process dynamics and disturbances. Results of actual measurements as well as results from on-line control experience are presented.

On-Line Identification of Process Dynamics *by E. B. Dahlin, p. 406.* Two methods similar to regression analysis are applied to the estimation of parameters in a dynamic process equation. One method uses a residual based directly on the differential equation for the process model. The second method forms the residual from the integro-differential equations derived by integration of the original differential equation with respect to time. The two methods are shown to be complementary in their sensitivity to process and measurement disturbances as well as to errors in the estimate of the process variable reference values. Certain parameters that are very sensitive with one method are shown to be much less sensitive with the other method. A combined method is developed which utilizes each one of the constituent techniques to estimate the parameter for which it has the highest accuracy. This not only permits identification with higher overall parameter accuracy, but also under many practical circumstances gives a convergent solution when one of the constituent methods would give a diverging solution having no practical value for updating control coefficients in an adaptive controller. It is shown that the estimate of the magnitude of a pole in a transfer function can be significantly improved by prefiltering the process input and output data with the same lowpass filter.

The paper presents a theoretical and experimental evaluation of the identification methods. Formulas are derived for the variances of the parameters permitting an estimation of the parameter accuracy in a particular test. The test data used has been collected from different control loops on paper machines. The disturbance level on some of the variables is very strong and a test signal-to-noise ratio as low as 0.5 can be encountered. The method is currently used in routine operation in adaptive paper machine control. It is in use on four control loops and has been tested on several other loops as well.

Sensitivity Constrained Optimal Control Synthesis *by W. J. Budurka, p. 427.* A constraint on the sensitivity to plant parameter uncertainties is introduced in the synthesis of optimal linear controls by adding a sensitivity function to a quadratic form performance criterion. The synthesis is carried out in the frequency domain using both conventional and Bode sensitivity functions; open-loop and closed-loop controls are of necessity treated separately because the sensitivity functions are different for each case. The optimal control based on the closed-loop Bode sensitivity is shown to satisfy a scalar Wiener-Hopf equation; the same type of equation is also satisfied by the optimal control based on the open-loop conventional sensitivity, but the response characteristics are different. Using the conventional closed-loop sensitivity, the optimal control is shown to satisfy an equation analogous to the Wiener-Hopf equation, but which is more difficult to solve because the control enters quadratically rather than linearly. Examples illustrate the application of derived results.

Synchronization of Traffic Signals in Grid Networks *by A. Chang, p. 436.* A method of synchronizing traffic signals interconnected in an arbitrary network is presented. The procedure consists of using a simplified mathematical model for traffic to relate the vehicular delay within the network to the signal parameters and then searching over these parameters to minimize the delay. The technique has been used to synchronize traffic signals in San Jose, California and has yielded a ten percent reduction in the average delay per car in comparison with the signal settings determined by the city traffic department with conventional engineering methods.

Design Principles for Sampled-Data Systems with Application to Attitude Control of a Large, Flexible Booster *by L. A. Gilson, E. F. Harrold, and F. G. Kilmer, p. 442.* This paper reviews *Z*-transform and *W*-transform theory and discusses in detail its application to dynamic compensation of linear sampled-data control systems. Both sampled-data (digital) and continuous-data (analog) compensator synthesis methods are discussed. With respect to digital compensator design, *w*-plane closed-loop pole positions are related to time response characteristics, analogous to the well known relationships between *s*-plane pole positions and time response parameters for continuous-data systems. An example is given which illustrates the design technique wherein time and frequency response characteristics are compared. A digital stabilization filter is derived for the attitude control system of a missile typical of the Saturn class.

A Computer-Operated Manufacturing and Test System *by J. E. Stuehler and R. V. Watkins, p. 452.* A computer system utilizing duplexed central processors and three types of satellite computer terminals has been developed for the control of manufacturing processes and product tests. The system was designed for use in a plant producing data processing equipment. The prime objectives of the project were (1) to reduce the time required for the plant to accept new products or product changes, (2) to reduce control and test equipment costs by using standard control and test equipment, and (3) to improve product quality through more uniform processes and tests. The objectives were met by using small, stored-program computer terminals to control individual tests and processes. These terminals are connected to a central computer system which assists with data processing and serves as an input/output device for the terminals.

The design and implementation of the system occurred in two phases. During the first phase the stored-program test terminal, a high-speed data transmission system, and a multiplexer were designed and installed on an IBM 1460 Data Processing System. A programming system was developed concurrently with the hardware. This system included a real-time monitor and application and utility programs which were written for operation in a time-shared environment. During the second phase of development a process control terminal, a data acquisition terminal, and a new multiplexer for duplexing two 1460 Data Processing Systems were designed and implemented. Also developed were shared file control units, an improved transmission system, and programming designed to effectively utilize the power of two computer systems on a real-time basis.

Properties of Insulating Thin Films Deposited by RF Sputtering *by W. A. Pliskin, P. D. Davidse, H. S. Lehman, and L. I. Maissel, p. 461.* The use of RF sputtering for the deposition of thin insulating films at relatively low temperatures (50° to 500°C) has been shown to yield films of very high quality. Methods for investigating the properties of RF-sputtered films are discussed in detail, and these indicate that such films are excellent stable insulators. Potential utility as an encapsulant for transistor structures has been demonstrated. Data for RF-sputtered SiO_2 and GSC-1 (an alumina borosilicate glass) are presented as examples of the properties obtained by this technique.

The Magnetization Mechanism in Single-Crystal Garnet Slabs Near the Compensation Temperature *by C. D. Mee, p. 468.* The magnetization mechanism has been studied in detail in single-crystal slabs of (111), (110) and (100) samples of gadolinium iron garnet (GdIG) near the compensation temperature. Using Faraday-effect and induction-type hysteresigraphs, the hysteresis loops have been measured in the sample plane and perpendicular to it, respectively. Measurements have been made at various temperatures, thus allowing the effects of variation of the saturation magnetization to be studied. In this way different relative magnitudes of shape and crystal anisotropy are obtained. Also, the effects of strain anisotropy variation are studied on the (111) sample. The hysteresis loops are correlated with the observed domain structures and a satisfactory theoretical model is described. Based on these studies, it is possible to estimate the approximate domain wall thickness and energy

in GdIG. Finally, an estimate of the exchange constant is made which is comparable with other estimates.

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Reverberation Chamber Determination of the Acoustic Power of Pure-Tone Sources *by G. C. Maling, Jr. and K. S. Nordby, p. 492.* A method was developed that is used to determine the acoustic power radiated by pure-tone and "nearly-pure-tone" sources in a reverberation chamber. The 3-dimensional standing wave sound field generated by a pure-tone source is sampled by a microphone that slowly sweeps a circular path in the chamber. The method relates the average value of the sound pressure at the peaks of the "sample" to its effective rms pressure. The acoustic power of the source is then readily calculated from the effective rms pressure, the volume of the chamber and its absorption.

The Electron Beam Scanlaser: Theoretical and Operational Studies *by R. A. Myers and R. V. Pole, p. 502.* This paper presents the theory, design, and initially observed operating parameters of the Electron Beam Scanlaser, a scanning laser device in which a modified electro-optic display tube selects one of many degenerate transverse modes of a flat-field conjugate resonator. The version considered uses a KDP crystal in the mode selector and an ionized mercury hollow cathode discharge as active element. Some observations reported are resolution (10 lines/mm); sweep rate (100 μsec/line); light decay time (2 msec, minimum); and power/spot (1W pulsed). Laser output power is about 30 dB greater than electron beam power.

Multiple-Curie-Point Capacitor Dielectrics *by R. A. Delaney and H. D. Kaiser, p. 511.* This paper reports an experimental study of the preparation of screened printed dielectric materials having high dielectric constants and a controlled temperature characteristic. The technique uses mixtures of sintered bodies which have different Curie points and which retain their identity after processing. Barium-strontium and barium-lead titanate mixtures have been prepared having a dielectric constant of about 500. This process has been used to produce negative-positive-zero, negative, and positive thermal coefficient bodies over various temperature ranges.

Two Interconnection Techniques for Large-Scale Circuit Integration *by A. E. Brennemann, A. V. Brown, M. Hatzakis, A. J. Speth, and R. F. M. Thornley, p. 520.* Studies of the feasibility of custom-interconnected, large-scale integrated circuits required the development of means for converting computer-generated wiring instructions into metallic conductors on a semiconductor wafer. The resulting equipment took two forms. In one, ultraviolet light serves to expose photoresists on a mechanically translated wafer; the other employs an electron beam. Both systems were adequate to produce two-mil-wide conductors, but differ in their potential for achieving high production rates or very thin lines.

Estimation of Temperature Rise in Electron Beam Heating of Thin Films *by T.-P. Lin, p. 527.* Expressions are given for estimating the transient temperature distribution in a thin film heated by an electron beam. Graphical presentations in terms of dimensionless (reduced) variables are included to aid in specific calculations for designing an electron beam for use as a heating tool.

A Numerical Integration Technique for Ordinary Differential Equations with Widely Separated Eigenvalues *by M. E. Fowler and R. M. Warten, p. 537.* An explicit nonlinear numerical integration method is presented for the solution of certain large systems of ordinary differential equations in which there is a large spread of time constants, the smallest one being real. The integration formulas are derived and some local truncation error data given for small step sizes. Some applications are discussed where the new technique saves considerable computation time over classical methods.

Power Conversion in Nonlinear Resistive Elements Related to Interference Phenomena *by E. M. Philipp-Rutz, p. 544.* This paper derives the power conversion in a nonlinear resistive element that is in series with linear resistors. The derivation of the power conversion is analogous to the Manley and Rowe analysis. The power at the fundamental and intermodulation frequencies is defined as the product of the Fourier coefficients of the current and voltage components at these frequencies. In the analysis, the Fourier coefficients are derived as functions of the generator voltage in a lumped-element circuit. To evaluate the Fourier coefficients, the relationship between current and generator voltage is expressed by a power series. The coefficients of the power series are given in the form of polynomials that are valid for nonlinear resistive elements with exponential characteristics.

For the investigation of interference phenomena, the equivalence between the lumped-element circuit and a microwave circuit is derived and the generator voltage is related to the power flux density carried by the incident waves intercepted by support structures. The transfer of power at the intermodulation frequencies to radiating structures is then described. Finally, the power at the intermodulation frequencies is evaluated numerically for different power levels in the incident waves. The computed values were verified experimentally.

On the Equation $i = i_0 [\exp \alpha (v - Ri) - 1]$ *by H. D. Mills, p. 553.*

Domain Wall Energy Measurements using Narrow Permalloy Strips *by J. M. Daughton, G. E. Keefe, K. Y. Ahn, and C.-C. Cho, p. 555.*

Propagation of Signals in Nonlinear Transmission Lines *by S. K. Mullick, p. 558.* This communication reports the

results of a theoretical investigation of the propagation of signals in transmission lines whose nonlinear parameters are distributed capacitance and conductance. Such lines have their physical counterpart in lossless transmission lines that are loaded with closely spaced transistor bases or junction diodes, and in waveguides filled with certain ferroelectric ceramic materials. The analysis is carried out by conventional perturbation theory, and therefore the nonlinearities and dissipation are necessarily assumed to be small. The conditions for the formation of shock waves in such lines are also derived.

On the Magnetic Properties of Sputtered NiFe Films *by B. L. Flur, p. 563.* Reproducibility and control of magnetic properties have been significant problems in the preparation of Permalloy films by cathodic sputtering. The data presented in this paper illustrate the reduced sensitivity to gaseous impurities that can be achieved by applying a suitable negative bias to an 81% Ni-19% Fe Permalloy film that is being deposited by dc sputtering. Results are shown which compare the magnetic properties as a function of deposition rate achieved with and without a bias potential applied to the film during deposition. Data are also presented showing the effect of film bias on magnetic properties when known concentrations of oxygen and nitrogen are present in the atmosphere during deposition. The evidence shows that the effect of the bias is to reduce the quantity of system atmosphere impurity included in the film. The bias technique has permitted, with good reproducibility, accurate experimental determination of the effect of such control parameters as substrate temperature on magnetic properties. (Wall motion threshold H_0, anisotropy field H_{k0}, and dispersion α_{90} are plotted as a function of substrate temperature.) In addition, data are shown which demonstrate the compositional control and simplicity of film thickness and deposition rate control which are inherent in the sputtering process.

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Some Computer Aspects of Meteorology *by H. G. Kolsky, p. 584.* A long history of large-scale scientific computing is associated with numerical weather prediction. Recently, interest in this field has been renewed as a result of international studies concerning the feasibility of a global observation and analysis experiment preliminary to the World Weather Watch. This paper describes the physical phenomena occurring in the atmosphere and the problems of modeling them for computer analysis. The numerical methods commonly used in general circulation models are described briefly and the relative advantages discussed. Finally, an analysis of the computer requirements for global weather calculations is developed and the need pointed out for very fast computers capable of executing the equivalent of hundreds of millions of instructions per second.

Some Studies in Machine Learning Using the Game of Checkers. II—Recent Progress *by A. L. Samuel, p. 601.* A new signature table technique is described together with an improved book learning procedure which is thought to be much superior to the linear polynomial method described earlier. Full use is made of the so called "alpha-beta" pruning and several forms of forward pruning to restrict the spread of the move tree and to permit the program to look ahead to a much greater depth than it otherwise could do. While still unable to outplay checker masters, the program's playing ability has been greatly improved.

Similar Motion of Two-Degree-of-Freedom Nonlinear Vibrating Systems with Nonsymmetric Springs *by K. E. Haughton, p. 618.* If similar motion occurs, it is demonstrated by a straight line (linear trajectory) in the configuration space whose orthogonal coordinates are the displacements of the masses in the vibrating system. Since the systems considered are conservative, all solutions of the equations of motion must satisfy the Principle of Least Action and its Euler-Lagrange equation. The solution of this equation defines a trajectory in configuration space, thus reducing the problem to one of geometry.

If the trajectory is linear, the Euler-Lagrange equation assumes a simple form. The form is further simplified if the coordinates of the configuration space are rotated and translated so that one axis coincides with the linear trajectory. Hence, if linear trajectories exist, it is necessary that the equation can be so simplified; it is sufficient that the rotation and translation be real.

One application of this analysis is shown for the case of a system whose anchor springs are air bearings, as used in a disk store.

SCEPTRE: A Program for Automatic Network Analysis *by S. R. Sedore, p. 627.* This paper describes the mathematical formulation of a computer program for automatic transient analysis of electronic networks. The formulation is based on the "state-variable" approach to network analysis and differs from other such programs primarily in the way that the network equations are manipulated to produce a solution. SCEPTRE includes a number of features aimed at providing greater flexibility and convenience for users of the program. Important among these features is that no prescribed equivalent circuit for active elements is required for program operation. Also, linearly dependent voltage and current sources in a network can be handled by the program, and provision has been made to allow a free-form format for input data. The paper includes a discussion of the program's ability to solve networks containing time-varying passive elements, and considers the factors that influence program running time.

Synthesis of Transfer Functions in a Prescribed Frequency Band *by W. R. Remley, p. 638.* A signal-processing system for synthesizing complicated transfer functions in a prescribed frequency band is described. The system consists of a multiplier followed by a closed loop containing a delay line

and phase modulator in series. One of the inputs to the multiplier is the signal to be filtered. The second input to the multiplier is periodic, the period being equal to the loop delay. One cycle of the periodic waveform is identical to the real part of the transfer function over a prescribed frequency band of width equal to the reciprocal of the loop delay. The imaginary component of the transfer function is the negative of the Hilbert transform of the real part, as in all physically realizable filters. Two applications of the system are discussed. It is shown how a continuously variable delay line and chirp filter can be synthesized using these techniques.

Exposure Control in a Multi-Stage Photographic System *by J. W. Boone and H. S. Todd, p. 643.* The use of controlled exposure in microfilming original documents offers a practical method for producing high-contrast images at subsequent printing stages with constant exposure times. This type of control, used for the three-stage generation of images in a developmental photo-image retrieval system, has given excellent results for documents which have uniform line-density contrast. For variable contrast documents, an analysis of the variations and variable exposures used in microfilming is necessary. The details of the analysis are described in this paper.

Two Remarks on the Reconstruction of Sampled Non-Bandlimited Functions *by C. J. Standish, p. 648.*

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The IBM SELECTRIC Composer: Philosophy of Composer Design *by G. A. Holt, p. 3.* The IBM SELECTRIC® Composer is a new kind of printing machine, much like a typewriter. This paper outlines the philosophy of design of the significant systems and mechanisms within the Composer and the primary elements needed to satisfy composition requirements, i.e., good print quality in a variety of classical type styles and sizes; variable vertical line spacing; justification; and an output of final copy that can be judged subjectively by printing experts and laymen alike.

The IBM SELECTRIC Composer: The Evolution of Composition Technology *by A. Frutiger, p. 9.* In this paper a discussion is presented on how the IBM SELECTRIC® Composer fits into the evolution of composition technology—from the calligraphers of the Middle Ages to the modern photocomposers. The advantages and limitations of the machine are discussed briefly with emphasis being placed on their meaning for the typographer.

The IBM SELECTRIC Composer: Letter Keyboard *by B. T. Crutcher and D. E. Sederholm, p. 15.* This paper describes the design of the letter keyboard for the IBM SELECTRIC® Composer. The design requirements were to provide an information transfer mechanism not only for character selection using the SELECTRIC Typewriter printing system, but also for proportional escapement selection and print impact velocity control. The keyboard was required to be exceptionally reliable, to have the positive SELECTRIC Typewriter touch characteristics, and to be consistent with the keyboard layout standards that are familiar to the operator or typist.

The keyboard that has been developed has a completely serial operating sequence. Each event in a sequence is positively latched as it occurs, and remains latched until its function is completed. This insures reliable information transfer without compromising speed or input-signal storage capability.

The IBM SELECTRIC Composer: Type Font Compatibility *by H. Pijlman, p. 26.* Because of the large number of type fonts required to support the IBM SELECTRIC® Composer program, it would not have been economical to manufacture separate type elements for each country in which the machine would be marketed. Also, because the total of the standard alphanumeric characters and the typical basic language requirements for all countries is much greater than could possibly be fitted on the Composer's 88-position type element, special Composer fonts had to be developed for various language group classifications. This paper describes the SELECTRIC Composer's development from a single-language system to a multilingual concept and details the problems involved in achieving compatibility, and thus type font interchangeability.

The IBM SELECTRIC Composer: Dead Key and Dead Key Disconnect Functions *by G. E. Siemer, p. 32.* Because diacritical marks are needed for the Latin and French-Latin type fonts, the IBM SELECTRIC® Composer required a means for printing certain characters without carrier escapement. This note discusses the "dead key" and "dead key disconnect" functions designed to fulfill this requirement.

The IBM SELECTRIC Composer: Mechanical Print Quality *by G. T. Slaughter, p. 34.* The design of an impact printing device (one which produces aesthetically pleasing copy) must include an optimal combination of mechanical design and supplies (ribbon and paper). This paper describes the evolution of design for both mechanisms and supply parameters which has led to the present standards of mechanical print quality in the IBM SELECTRIC® Composer.

The IBM SELECTRIC Composer: Statistical Evaluation of Printing Alignment *by M. Prewarski, p. 41.* This paper describes the measurement and evaluation of print alignment for the SELECTRIC® Composer, and discusses the suitability of statistical techniques for achieving both. This paper deals extensively with techniques and procedures for collecting data; however, it is not intended to define a generalized method for statistical evaluation. Printing alignment is shown to be described objectively and precisely by the distribution of measured misalignment; misalignment is precisely defined.

The IBM SELECTRIC Composer: Proportional Escapement Mechanism *by B. W. Miles and C. C. Wilson, p. 48.* The IBM SELECTRIC® Composer's escapement system employs rotating elements, rather than the conventional rack system, to provide the required displacement. This permits the basic unit of escapement to be varied, and allows the number of units per escapement cycle to vary in proportion to character width. In this paper the authors discuss the machine requirements that led to this approach and describe the elements that have evolved. The analysis used to evaluate the design (and modify it to some extent) is also recorded, in a separate section.

The IBM SELECTRIC Composer: Memory Backspace *by C. N. Van Avery, p. 60.* This paper describes the design of the memory backspace system as it now appears in the IBM SELECTRIC® Composer. The memory backspace system employs a sensing pawl mechanism in conjunction with the escapement pinwheel and the unit backspace mechanism to provide character-by-character backspace capability. By sensing set pins on the pinwheel, the mechanism "remembers" the location of previously typed characters and permits the carrier to be returned precisely to any print position within the memory "length" without operator measurement or visual alignment.

The IBM SELECTRIC Composer: Development of the Rebound Governor *by N. Cail, p. 65.* Rebound of the escapement system of the SELECTRIC® Composer after

escapement is limited by the rebound governor, a device consisting of an overrunning clutch and a mass that is coupled to the system only during rebound. The development of the rebound governor is described in this paper and its effect on the escapement system is shown by oscilloscope traces of system displacement versus time.

The IBM SELECTRIC Composer: Justification Mechanism *by J. S. Morgan and J. R. Norwood, p. 68.* This paper describes the development and design history of the SELECTRIC® Composer justification mechanism. The authors present a brief definition of justification and how it relates to the printing industry; the requirements imposed upon a justification device that are peculiar to the SELECTRIC Composer; a description of the justification mechanism and its design, development and testing; and a final evaluation of the design relative to the attainment of its designated objectives, both as a mechanism and as a component of the SELECTRIC Composer.

The IBM SELECTRIC Composer: Multiple Index Mechanism *by R. D. Mathews, p. 76.* When high-quality printed copy is desired, the ability to use variable styles of type in one printing system is a fundamental requirement. This feature has existed to a limited extent for some time in low-cost, cold-type printing equipment and typewriters, and has been notably realized in the changeable typehead of the IBM SELECTRIC® Typewriter. The ability to vary type *size,* however, is rarely found in such systems and has been restricted for the most part to commercial hot-type equipment or to manual methods. To remove this restriction in the IBM SELECTRIC Composer, it was necessary to design an index mechanism which would provide variable line-to-line increments. Increment selection was to be flexible enough to accommodate several sizes of type, but it had also to be reliable and easily controlled by the operator. The design which has resulted and is described in this paper is a dual-ratchet, planetary gear system. Platen increments of from 5 to 20 "points" can be selected, and the platen can be indexed manually one point at a time. Other features are also provided, including a "carriage-return, no-index" which permits changing styles on the same line of type without manual "rollback."

The IBM SELECTRIC Composer: Carbon Ribbon Feed Mechanism *by J. W. Spears and J. C. Rogers, p. 87.* High quality impact printing requires that a sufficient supply of printer ink be presented to the print element for each character. It is also required that this supply of ink last for a reasonable length of time. To enable the IBM SELECTRIC® Composer to meet the standards considered necessary under these criteria, it was necessary to increase the character yield per ribbon by a factor of two over that which was provided by the IBM SELECTRIC Typewriter. To do this a new constant ribbon tension control device had to be designed to eliminate the inertia and geometry effects associated with the larger composer ribbon spools. It was also necessary to eliminate ribbon feeding on no-print or spacebar operations and to provide various load controls.

Force-Frequency Coefficient of Singly Rotated Vibrating Quartz Crystals *by J. M. Ratajski, p. 92.* Frequency perturbations in vibrating quartz crystals, caused by externally applied forces, have been investigated for some time. The parameters affecting the force-frequency sensitivity were recently established and evaluated, making possible the derivation of a normalized coefficient K_f. An empirical chart, showing the coefficient K_f for all singly rotated crystals, $(yxl)\,\theta$, is presented for all directions of force in the azimuth angle ψ. The maximum force-frequency coefficient is found to be $|K_f| \cong 30 \times 10^{-15}\ (msN^{-1})$ for angles $\theta = +17°, +26.5°$ and $+64°$. A crystal cut $(yxl) - 18.5°$ shows a constant coefficient $K_f = +5.3 \times 10^{-15}\ (msN^{-1})$ for all angles of ψ. Coefficients $K_f(\psi)$ for BT-, Y- and AT-cut crystals are also shown on separate graphs.

The force-frequency behavior of every crystal cut in the singly rotated Y-cut group can be determined from the chart. The chart is a useful tool for the design of frequency standards and precise force-sensing elements. More significantly, the chart provides normalized experimental data to form a basis for a theoretical treatment of the force-frequency effect.

Some Magnetic Properties of Vacuum-deposited Coupled Films *by K. Y. Ahn and J. F. Freedman, p. 100.* The magnetic properties of vacuum-deposited multilayer films constructed in a closed-flux configuration in an integrated structure have been studied as a function of: a) film thickness; b) substrate temperature, and c) the character of the conductor metals. It is found the static magnetic properties of the magnetic layers depend on the material in the previous layers as well as the thickness and deposition temperature of those layers. Techniques of optimizing and controlling the magnetic properties are discussed.

Shear Stresses in a Notched Circular Disk *by T.-C. Ku, S. S. So, and W. E. Nickola, p. 110.*

The Resonistor: A Frequency Selective Device Utilizing the Mechanical Resonance of a Silicon Substrate *by R. J. Wilfinger, P. H. Bardell, and D. S. Chhabra, p. 113.* This communication describes an approach to tuned monolithic circuitry which utilizes the mechanical resonance of a silicon substrate. The proposed device is compatible with monolithic technology and will operate from a few hundred cycles to hundreds of kilocycles. The basic device consists of a silicon cantilever mechanically deflected by electrically induced thermal expansion. Diffused silicon piezo-resistive elements are used to detect stress in the cantilever and provide an electrical output. Maximum stress and electrical output occur when the cantilever is driven at its mechanical resonant frequency.

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Method for Estimation and Optimization of Printer Speed Based on Character Usage Statistics *by E. B. Eichelberger, W. C. Rodgers, and E. W. Stacy, p. 130.* Many high-speed printers now in the field and under development use a constantly moving chain or train containing the characters required in the printing process. Generally they skip to the next line whenever the last character on a given line is printed. Since individual character usage varies widely, it may be possible to increase the printing speed by repeating high-usage characters more frequently on the chain than low usage ones.

This paper presents an analytic method of accurately estimating the printing speed of a chain printer for any character arrangement and describes a technique for determining the number of copies each character should have on the chain so that the printer will operate at or near maximum speed. Using these methods, significant increases in printing speeds have been obtained for actual applications.

Polymer Dielectric Films *by L. V. Gregor, p. 140.* Polymer dielectric films, ranging in thickness from less than 100 Å to several microns, have become increasingly useful for basic investigations of surface phenomena and thin film electrical conductivity and for thin film electronic device and circuit development. The preparation and characterizing properties of thin polymer films are discussed with particular emphasis on recent developments in such areas as ultraviolet surface photolysis, electron bombardment, gaseous electrical discharge, and special chemical processes. Previously unpublished data on certain aspects of polymer dielectric films are presented, and present and potential applications are briefly reviewed.

Computer Algorithm for Spectral Factorization of Rational Matrices *by W. G. Tuel, Jr., p. 163.* An algorithm is derived for the numerical spectral factorization of matrices arising in optimal filter design. The method uses a bilinear transformation to convert the factorization problem into a stable nonlinear difference equation of the Riccati type. The computer solution of several examples is presented to illustrate the technique.

Automatic Focus Control of Charged-Particle Beams *by M. H. Dost, p. 171.* The focusing mechanism for charged-particle beams is analyzed and its mathematical model is derived. Two control concepts for focusing electron beams are shown and the details of the feedback system for automatic focus control in the electron-beam recorder of an IBM photo-digital mass storage system are described (Fig. 9). Included are a representation of the mathematical system and the computer simulation results obtained from the digital simulation program DSL/90.

Application of Finite Geometry in File Organization for Records with Multiple-Valued Attributes *by S. P. Ghosh and C. T. Abraham, p. 180.* The schemes for organizing binary-valued records using finite geometries have been extended to the situation in which the attributes of the records can take multiple values. Some new schemes for organizing records have been proposed which are based on deleted finite geometries. These new schemes permit the organization of records into buckets in such a manner that, by solving certain algebraic linear equations over a finite field, it is possible to determine the bucket in which records, pertaining to two given values of two different attributes, are stored. Since the bucket identification required for the storage of record accession numbers is based on the combination of attribute values, the file does not require any reorganization as new records are added. This is a definite advantage of the proposed schemes over many key-address transformation procedures wherein the addition of new records may lead to either a drastic revision of the file organization or significant reduction of retrieval effectiveness. The search time for the new schemes are very small in comparison to other existing methods.

The Study of Laser-induced Absorption of a Secondary Light Beam in Molecular Liquids and Solutions *by M. W. Dowley and W. L. Peticolas, p. 188.* New techniques are shown for determining the change in absorption spectrum of molecular liquids when a laser beam is passed through the sample. Two-photon absorption measurements are shown for α-chloronaphthalene. The experimental arrangement (Fig. 3) features a high signal-to-noise ratio and permits study of explicit time dependence of the absorption signal.

Reflectivity Thickness Corrections for Silicon Dioxide Films on Silicon for VAMFO *by W. A. Pliskin and R. A. Wesson, p. 192.*

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Computation of Molecular Properties and Structure *by A. D. McLean and M. Yoshimine, p. 206.* A discussion of general-purpose computer programs in theoretical chemistry is given, followed by a description of the procedures adopted in one such program written by the authors. Specific details on the use of the program for computing molecular wave functions and properties for closed-shell linear molecules are presented. The details of a method for computing the axial components of the static electric polarizability and shielding factor tensors are given. A "Table of Linear Molecule Wave Functions" is available, on request to the authors, as a supplement to the paper. This tabulation was made with the program described in the paper and is the most extensive compilation of molecular wave functions currently available.

Redundant Alphabets with Desirable Frequency Spectrum Properties *by E. Gorog, p. 234.* When alphabets of digital symbols are used to represent information for data processing, storage, and transmission, redundancy in the alphabets is traditionally used for the purpose of error compensation. This paper deals with alphabets of redundant codes, both binary

and higher level, where the emphasis is on using redundancy to produce code alphabets with unique properties in their frequency spectra that can be exploited in the design of the system in which they are used.

In particular, techniques are presented for synthesizing alphabets that produce spectral nulls at frequencies $1/kT$, where T is the duration of a word element. Some of the interesting alphabets are a 10-word, 5-bit alphabet with spectrum zero at $1/2T$; a 10-word, 6-bit alphabet with spectrum zero at $1/3T$; a 36-word, 8-bit alphabet with zero at $1/4T$; and a 36-word, 8-bit alphabet with zeros at both 0 and $1/2T$.

A Two-Dimensional Mathematical Analysis of the Diffused Semiconductor Resistor *by D. P. Kennedy and P. C. Murley, p. 242.* A two-dimensional mathematical analysis is presented of the electrical properties of the diffused semiconductor resistor. An important conclusion is that substantially more electric current crowding exists within this semiconductor device than heretofore suspected, particularly in the vicinity of the ohmic contacts. Considered in this analysis is the influence on the electrical characteristics of various impurity atom distributions arising from a two-step diffusion process. The results of this investigation are presented graphically.

High-resolution Positive Resists for Electron-beam Exposure *by I. Haller, M. Hatzakis, and R. Srinivasan, p. 251.* This paper examines the utility of four newly proposed positive resists whose processing combines electron-beam-induced degradation of certain polymers and, subsequently, *in situ* fractionation according to molecular weight. Positive-resist action in four systems formulated on this concept has been demonstrated. Typical sensitivity in electron-beam exposure is 10^{-4} coulomb/cm^2. Two resists exhibit resolution better than 1 micron. One resist investigated in detail yields extremely clean edges in electron-beam exposure, is resistant to hydrofluoric acid etching baths, and appears otherwise applicable to the fabrication of circuit elements of submicron size.

Effects of Lasers on the Human Eye *by W. L. Makous and J. D. Gould, p. 257.* In dealing with the relationship between human vision and lasers, this largely theoretical paper places particular emphasis upon the use of lasers within the normal operating range of the visual system, and upon the mechanisms by which laser radiation can cause threshold damage to the eye. Parallel but subordinate sections present some fundamentals of laser radiation, of the relevant aspects of the visual system, and of unit systems for the specification of laser output. A new approach to understanding laser radiation damage to the eye is developed by means of a model limited to conditions existing only at the threshold of damage. It is shown that such threshold damage to the visual system is primarily due to the effects of heat alone, but that photochemical effects and acoustic shockwaves can potentially be a cause of the threshold damage that cannot be entirely rejected under all conditions. A theoretical estimate of retinal irradiance for threshold damage is made and shown to be consistent with empirical findings. A survey of empirically determined damage thresholds is presented. A valid method of computing retinal irradiance from a laser is given, and the direction and magnitude of errors in earlier formulations are pointed out.

Room Temperature Delay Times in Diffused Junction GaAs Injection Lasers *by J. C. Marinace and K. L. Konnerth, p. 272.* One nanosecond room temperature delay times at current levels slightly above threshold have been obtained in GaAs injection lasers using a two step diffusion process. Copper contamination is found to leave the delay time unchanged, but increases the rise time.

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Automatic Dynamic Response Analyzer *by P. E. Stuckert and G. F. Bland, p. 286.* The Automatic Dynamic Response Analyzer (ADRA) is a laboratory tool for developing improved methods of characterizing and measuring the dynamic performance of integrated circuit logic packages. ADRA consists of ensembles of computer controlled electronic equipment which provide a suitable electrical environment for the logic unit under examination, subject the unit to appropriate patterns of shaped pulses, measure and digitize the input/output waveforms, and process the resulting data. This paper describes the ADRA system, its organization and hardware characteristics, and an example of its use.

An Application of the Automatic Dynamic Response Analyzer *by K. Maling and H. D. Schnurmann, p. 300.* An experiment to obtain the coefficients of a circuit delay equation was designed and implemented on the ADRA/M44 system in order to gain experience in the system's use. The process involves automatic calibration and diagnostic procedures, data collection under computer control and multivariate regression analysis. Some conclusions are drawn about the planning and use of computer controlled instruments such as ADRA.

A Balanced Capacitor Read-Only Storage *by S. A. Abbas, J. K. Ayling, C. E. Gifford, R. G. Gladu, T. C. Kwei, and W. J. Taren, p. 307.* The design of a control storage system of 90 nsec access time and 200 nsec cycle time with permanently stored microinstructions is described. The storage medium used is the capacitive coupling between two groups of orthogonal conductors forming an information plane and a sense plane. There are 2816 words of 100 bits each, divided over two gates. The selection of an address line in the information plane is achieved through a transistor selection matrix. The output signal is sensed differentially at the mid-point of the sense line, which is matched at both ends. The sense amplifier output plus a "strobe" pulse set a latch for a portion of the cycle time and this provides the necessary inputs to the central processing unit. The major contributions

to noise, such as sneak-path noise and select noise, are discussed and evaluated. The timing of the different pulses necessary to drive the array and the resulting outputs are explained and the marginal effects of time and amplitude variations are considered. Information can be changed off-line by replacing bit planes. Transcription of information in the bit planes is fully automated and can be speedily accomplished.

A New Technique for Wide-Band Video Recording *by W. T. Frost and C. T. Masters, p. 318.* An efficient means for distributing the information contained in a wide-band analog signal over two limited bandwidth channels is provided by using frequency modulation and "zero-crossing counting." The new technique should accommodate at least twice the bandwidth that can be recorded or transmitted by the usual FM methods. Experimental results with a two-channel magnetic tape system confirm this expectation.

Pressurized High-Speed Development of Diazo Films *by J. W. Boone and R. B. Mulvany, p. 323.* The combination of a new high-speed process and developer unit which uses pressurized anhydrous ammonia gas offers a significant increase in the speed of developing diazo photomaterials. In addition to being up to 100 times faster than conventional ambient-pressure ammonia development processes, the new process and developer provide both flexibility and uniformity of sensitometric characteristics.

The unpleasant odor and corrosive character of ammonia gas required a means for positively sealing the film surface to the processing device and a means for disposing of residual ammonia gas remaining in the device at the end of the processing cycle. A developer platen, designed to meet these needs, also achieves uniform image development by utilizing the entering flow of ammonia gas to wash entrapped ambient air from the film surface and into a small reservoir. The process and its relatively simple hardware have been incorporated into an experimental photo-image converter to provide "on-line" input and output of photo-images from a random access image file. The process and a wash-type developer are used in the IBM 9950, 9954 and 9955 diazo aperture card copiers.

An Application of the Cooley-Tukey Algorithm to Equalization *by B. Meister, p. 331.* A new method is proposed to determine the tap settings of a delay-line filter for distortion correction of digital data after transmission by a voice line. The procedure described achieves approximately the optimal tap settings by solving a system of linear equations with a circulant matrix of coefficients. When the fast Fourier transform algorithm of Cooley and Tukey is used, the resulting quantity of computations is considerably smaller than in other known methods. Therefore, much faster equalization can be achieved.

Implicit Implementation of the Weighted Backward Euler Formula *by H. H. El-Sherif, p. 335.* This communication describes how the weighted backward Euler formula, as applied to analyze electromechanical systems, can be implicitly implemented by replacing capacitors and inductors by resistors and voltage or current sources, respectively, and by replacing the driving functions by their first differences. This replaces the set of differential equations, which describes the capacitive voltages and the inductive currents, by a set of algebraic first difference equations.

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The IBM 1975 Optical Page Reader Part I: System Design *by R. B. Hennis, p. 346.* The IBM 1975 Optical Page Reader, specially built for the Social Security Administration, reads over 200 fonts from quarterly employer reports printed by electric and manual typewriters, business machines, and high-speed printers. Since the SSA has no control over the means used by employers to prepare the reports, many variations in print quality are present. This paper discusses the problems involved in planning and developing a system to read these reports and summarizes the design of the specialized video signal processing circuits and the character recognition logic that are used in the system. Two companion papers treat the latter topics in more detail. Also discussed in the paper is a management information system that permitted detailed analysis of experimental data and accelerated the development process.

The IBM 1975 Optical Page Reader Part II: Video Thresholding System *by M. R. Bartz, p. 354.* An adaptive video thresholding system is used in the Page Reader to minimize recognition failures due to contrast and line width variation. The main threshold operator is a linear function of the average contrast over a specified area. Adjustments to the threshold level are made by circuits that compute the average line width in a character, and by circuits that filter out spatial noise in the vicinity of the character. The different types of print quality distortions predominant in typewriter printing and business machine printing are handled by switching between different sets of threshold operators.

The IBM 1975 Optical Page Reader Part III: Recognition Logic Development *by D. R. Andrews, A. J. Atrubin, and K.-C. Hu, p. 364.* The design approaches which were used to specify feature measurement logic, recognition reference standards, and decision functions for a multifont character recognition system are discussed. The importance of an intuitive approach to design, as opposed to a fully automated approach, is emphasized. The nature of the problem required an intimate interaction between the designers, who investigated complex pattern recognition problems and proposed design alternatives, and the computer, which relieved the designer of routine testing and evaluation of the tentative design.

Time-Optical Control of a Moving-Coil Linear Actuator *by C. J. Brown and J. T.-S. Ma, p. 372.* The time-optimal control problem for a moving-coil linear actuator has been worked out by means of functional analysis and a related graphical procedure requiring only data from an impulse response. On the basis of experience with a test model, there is good correlation between the theoretical and the experimental methods. While the latter is accurate over only very short distances, the usefulness of the technique can be extended as needed by operating the system in piecewise linear fashion. The nonlinearity of the coil inductance can be handled under computer control by including in the program the inductances for successive segments of travel.

Development of the IBM Magnetic Tape SELECTRIC Composer *by D. A. Bishop, R. S. Heard, R. E. Hunt, J. E. Jones, and R. A. Rahenkamp, p. 380.* The IBM Magnetic Tape SELECTRIC® Composer (MT/SC) is a direct-impression (or "cold-type") typesetting system that combines the recording capabilities and automatic operation of the Magnetic Tape SELECTRIC Typewriter with the proportional spacing, justification and multiple-type-size features of the SELECTRIC Composer. Intended to permit high-volume, high-quality composition at moderate cost for users of offset printing methods, its design and development are described in this paper.

On the Measurement of Impurity Atom Distributions in Silicon by the Differential Capacitance Technique *by D. P. Kennedy, P. C. Murley, and W. J. Kleinfelder, p. 399.* A mathematical analysis is presented on the measurement of an impurity atom distribution in silicon by the differential capacitance technique. This analysis shows some inherent errors that can arise when the technique is applied to material containing a small impurity atom density. An important conclusion is that the differential capacitance measurement establishes the distribution of majority carriers, rather than the distribution of impurity atoms; therefore this measurement technique is applicable only in regions of semiconductor material exhibiting charge neutrality.

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Error Detection and Correction in a Photo-Digital Storage System *by I. B. Oldham, R. T. Chien, and D. T. Tang, p. 422.* An error-correction system has been implemented for data stored in the IBM Photo-Digital Storage System. Hardware is used for encoding and error detection, and a processor-controller is used, on a time-sharing basis, for error correction. A Reed-Solomon code is used to obtain a very low error rate in spite of flaws affecting the recorded bits. This approach is applicable to systems which require complex codes and have a data processor available on a time-sharing basis.

Small-signal Stability Criterion for Electrical Networks Containing Lossless Transmission Lines *by R. K. Brayton, p. 431.* A stability criterion is derived for networks containing lossless transmission lines as well as the usual lumped electrical elements. The criterion is stated in terms of the transmission line parameters and scattering matrix measurements made at the terminals of the lumped part of the network. The mathematical proof of the stability theorem involves some new results concerning a special system of difference-differential equations. Another stability criterion is derived in terms of more general input-output measurements.

Calculation of Liquid Droplet Profiles from Closed-Form Solution of Young-Laplace Equation *by T.-C. Ku, J. H. Ramsey, and W. C. Clinton, p. 441.* A closed-form solution is obtained for a two-dimensional version of the Young-Laplace equation governing the shape of the interface between immiscible liquids. This solution enables designers of liquid junctions (in, for example, soldering or ink printing applications) to calculate profiles using certain junction dimensions as boundary conditions in the equations. Calculated profiles are superimposed on silhouettes of liquid junctions to show the accuracy of the solutions (±5%). The paper also introduces a parameter called the coefficient of retardation which was found convenient in accounting for all the factors that permit variable contact angles to be observed in a given solid-liquid-air system.

X-ray Diffraction Topography of Germanium Wafers *by A. P. Segmüller, p. 448.* X-ray diffraction topography in transmission and reflection has been employed to analyze crystal faults and stresses in germanium wafers caused by deposition of oxide layers, epitaxy and planar diffusion. Localized diffusion of arsenic, gallium and phosphorus normally does not introduce stresses sufficiently high to generate dislocations in germanium (011) wafers. However, heat treatment of germanium wafers covered with a SiO_2 film causes high stresses which are often relieved by plastic deformation.

Photo-*n-p* Junctions in ZnTe *by F. F. Morehead and B. L. Crowder, p. 458.* We have demonstrated ZnTe devices with efficient (about 1%) light emission at 77K in which the injection mechanism is a forward-biasd photo-*n-p* junction. In one, Al and Cd are diffused into highly *p*-type ZnTe:P to produce an Al-doped region 70 μm deep with a 20 μm surface layer of average composition $Zn_{0.6}Cd_{0.4}Te$. Light emission (575 nm) is observed for 2.5 V. Similar results are obtained when Al alone is diffused in from an evaporated layer to a depth of about 50 μm. This latter device was earlier thought to operate by avalanche injection. Both structures with In contacts to the Al layer give open-circuit photovoltages of over 1.8 V at 77K. The all-ZnTe device, however, requires over 7 V to sustain light emission. While it is possible that efficient ZnTe devices made by vapor diffusing the Al are avalanche injection structures, efficient avalanche injection in a II-VI device has yet to be conclusively demonstrated.

Algebraically Generalized Recursive Function Theory *by H. R. Strong, p. 465.* The Uniformly Reflexive Structure (URS) introduced by E. G. Wagner is, for this paper, a nonassociative algebra consisting of a domain and a binary operation satisfying the following axioms:

0. $(\exists *)(\forall a)[a \cdot * = * \cdot a = *]$;

1. $(\exists \psi)(\forall a, b, c, d)$

$\times [\psi \neq * \ \& \ ((a \neq * \ \& \ b \neq * \ \& \ c \neq * \ \& \ d \neq *) \rightarrow$

$((a = d \ \& \ (((\psi \cdot a) \cdot b) \cdot c) \cdot d = b)$ or

$(a \neq d \ \& \ (((\psi \cdot a) \cdot b) \cdot c) \cdot d = c)))]$; and

2. $(\exists \alpha)(\forall b, c, d)[\alpha \neq \psi \ \& \ ((b \neq * \ \& \ c \neq * \ \& \ d \neq *) \rightarrow$

$((\alpha \cdot b) \cdot c \neq * \ \& \ ((\alpha \cdot b) \cdot c) \cdot d = (b \cdot d) \cdot (c \cdot d)))]$.

Wagner showed that these structures generalize much of Recursive Function Theory (RFT).

In this paper the functions "computed" by a URS are the functions given by left multiplications by elements of the URS. A family of functions is said to form a URS if it is the family of left multiplications of some URS. Axioms for Basic Recursive Function Theory are given characterizing those families of functions which form URS's. The Partial Metarecursive Functions and the Computable Functionals of McCarthy are shown to form URS's.

An investigation of notions analogous to the "recursively enumerable" notion in RFT shows that if any splinter ("successor set") of a URS is semicomputable, then all are. A partial analogue to the Rice-Myhill-Shapiro Theorem is proved for URS's satisfying an axiom corresponding to Kleene's "indefinite description." Finally, a study of pairing functions leads to work analogous to Rogers' on Gödel numberings and generalizes similar work of Wagner.

Design and Fabrication of Subnanosecond Current Switch and Transistors *by V. A. Dhaka, p. 476.* A junction-isolated integrated circuit in silicon is described, having a switching speed of 320 picoseconds in a package which by itself causes a 120 ps delay. The design of the transistor used in this circuit was obtained by simulating the transistor as a computerized, two-dimensional distributed model. The improvements required in the transistor technology were thus predetermined and the design was realized without a large number of iterations. It is shown that the primary parameters affecting the performance of the transistor are (a) mobile carrier storage in the emitter-base junction; (b) emitter crowding; (c) stretching of the base into the collector at high forward-current densities and (d) conductivity modulations in the active base region. The resulting transistors have a cut-off frequency of 7.15 GHz at $V_{CB} = 2$ V and $I_C = 20$ mA. The total number of impurity atoms forming the emitter and the base region are 5.57×10^9 and 5.7×10^5, respectively.

New Annealing Effects on the Bulk Corrosion Potential of Germanium *by R. Gereth and M. E. Cowher, p. 483.* The corrosion potential (U_k) of n-type Ge with donor concentrations less than 10^{18} cm^{-3} was drastically changed ("ΔU_k effect") by heat treatments between 600 and 800°C. The formation of recombination centers due to Cu contamination is probably the principal cause.

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Foreword *by J. D. Swalen, p. 2.*

Computer-operated X-ray Laboratory Equipment *by H. Cole, p. 5.* Many instruments in research laboratories are now operated under varying degrees of computer control, not merely to accumulate and store data, but to obtain information about the sample sooner. The need for the scientist to interact with the computer is then as important as the instrument-computer interaction. This requirement leads to strong differences in implementation between laboratory automation and process control, and also suggests that the scientist must consider his over-all information needs as well as his instrument needs. A control computer shared by several people doing x-ray diffraction and fluorescence work is used as an example to illustrate some of these aspects of laboratory automation.

Automation of a Wide-range, General-purpose Spectrophotometric System *by P. M. Grant, p. 15.* The application of an IBM 1800 computer to the control and data acquisition functions of a wide-range spectrophotometric system is described. The optical part of the system is designed primarily for solid-state spectroscopy in the reflectance mode, the energy range of interest being roughly 1 to 12 eV (10^4 to 10^5 cm^{-1}). The operations of the computer include regulation of the wavelength setting, determination of the system gain, analog-to-digital conversion of the output signal, and positioning of the sample and detector. Two experimental configurations are employed, depending on whether or not the sample and detector are to remain stationary or to be repositioned during a run. The former holds for electroreflectance, fluorescence, and photoconductivity studies, while the latter pertains to ordinary reflectance and transmittance measurements. The principal advantage to be derived from on-line computer control of such experiments, besides more rapid accumulation and reduction of data, is the improvement in signal-to-noise ratio by averaging many repetitive scans over the same energy range. The emphasis in this paper is on the software used to implement these operations.

New Research Techniques for the Life Sciences *by G. D. McCann, p. 28.* A data collection and analysis system, using a high-speed, general-purpose digital computer, has been developed at the California Institute of Technology and applied to the study of visual processes of pattern recognition in living nervous systems. The experimental technique employs a rapid, flexible method of neural network modeling that permits an analysis of network functional behavior and a comparison with experimental data. Some details are given of research on neural activity in the visual system of the insect order *Diptera.*

Computer-assisted Spectroscopy *by B. Johnson, T. Kuga, and H. M. Gladney, p. 36.* The logical and timing requirements and the control circuitry of spectrometers in all energy ranges, chromatographs, scanning interferometers and microdensitometers, and a large class of related experimental apparati are very similar. From the standpoint of on-line computation and control, they can be considered parametric variations of a single experiment. With a magnetic resonance spectrometer as an example, we describe briefly the central, common elements of the necessary computer-instrument interface and of adequately flexible and open-ended control programs. Some examples of results follow.

Combination of On-line Analysis with Collection of Multicomponent Spectra in an On-line Computer *by N. P. Wilburn and L. D. Coffin, p. 46.* A digital computer has been interfaced to four 256-channel analyzers. All functions of normal multichannel analyzers have been reproduced by suitable coding. In addition, a weighted least-squares method for estimating on line the contribution of individual radionuclides in a multicomponent pulse height spectrum has been incorporated. Details of the mathematics and coding methods, which include special modifications to an existing FORTRAN system for on-line use, are described.

An Interactive Graphics System for Nuclear Data Acquisition *by J. Birnbaum, T. Kwap, M. Mikelsons, P. Summers, J. F. Schofield, and F. Carrubba, p. 52.* The graphics terminal described was developed for low-energy nuclear-physics data acquisition and control, and is currently in use at the Yale University Wright Nuclear Structure Laboratory as part of an IBM System/360 Model 44-based system. It is comprised of dual cathode ray tube displays, a light pen, and function keyboard, and includes character generation, display simulation, and photographic facilities. It is capable of plotting 200,000 points per second with variable intensity. The display programming structures, which support highly interactive communication between physicist and computer, are discussed in detail. A data acquisition programming system permits the creation and manipulation of self-describing global data and display entities. Examples of the resultant increased experimental sophistication and efficiency are presented.

Simulation and Experimental Research *by J. J. Byerley and T. Z. Fahidy, p. 61.* The usefulness of computer simulation in interpreting and extending experimental information is presented via a practical example taken from the area of chemical metallurgy.

Computer Facilities for the Laboratory *by T. R. Lusebrink and C. H. Sederholm, p. 65.* Digital computers have become indispensable aids for many laboratory disciplines, allowing the performance of experiments which would be infeasible without the aid of a computer. Until recently, these computations have usually been carried out off-line, i.e., experimental data has been acquired in real time and subsequently processed on a large central computer. Small, relatively inexpensive digital computers first entered the

laboratory as a substantial aid in real-time acquisition of data and control of experiments. Such computers, however, suffer severe limitations with regard to ultimate processing of the data. Hence the data processing must still generally be done on a large computer.

To realize the full potential of computer-instrument interaction, one should use the computer to: acquire data while performing requisite control of an experiment; calibrate, reduce, and compare the data with files of known physical parameters or theoretical calculations; and finally, produce desired reports and documentations of the experiment. In order to obtain results soon enough to effect the next experiment, i.e., in minutes, or at most, tens of minutes, all of the foregoing steps should preferably be carried out in a single computer.

Fulfilling all of these needs requires a computer too large and expensive to be dedicated to most single experiments. Therefore, a computer shared among several instruments is required. A computer system which simulates the independence of small dedicated computers, but which is also capable of performing medium- to large-scale computations when they are required, is most desirable.

Of course, many of these statements are controversial, and in order to investigate the validity of this approach an experimental computer system has been designed and implemented specifically for automation of multiple laboratory instruments in a time-shared mode. Experience gained from the simultaneous operation of a mass spectrometer, a nuclear magnetic resonance spectrometer, and two gas chromatographs is presented. The application programs and some proposed augmentation of these programs are also discussed.

Use of a Time-sharing Computer in Nuclear Chemistry *by J. Fryklund and W. Loveland, p. 75.* The Oregon State University computer-analyzer system couples the advantages of on-line data acquisition and analysis with the low cost of a time-sharing computer. The system operates in two modes. In Mode A, a 4096-channel analyzer serves as a data acquisition and buffer storage device with the contents of the analyzer memory being transmitted via telephone lines to the Oregon State University computer for analysis. In Mode B, the correlated outputs of N analog-to-digital converters (corresponding to an N-parameter event) are transmitted to the computer in real time for storage and analysis. Additional information, programming and computations may be entered at any time from a remote terminal console. The results of the data analysis can be returned immediately to the remote terminal console or to any regular computer output device. This system has the advantages of being able to utilize the full facilities of a large computer, its FORTRAN compiler, etc., for on-line data acquisition and analysis while avoiding the responsibilities of hardware maintenance and systems programming for the nuclear chemists.

Computer-controlled Optical Spectrometer *by D. M. Hannon, D. E. Horne, and K. L. Foster, p. 79.* Hardware developed to implement the computer control of a single-beam monochromator operating under a time-sharing system is described. A stepping motor and associated circuitry yield very precise wavelength positioning in an open loop configuration and with a minimum of computer use. The circuits used to position and step the wavelength are described in detail.

Growth of a Laboratory Computer System for Nuclear Physics *by J. F. Mollenauer, p. 87.* A computer system may typically be expected to progress through a cycle terminating in overloading. The experience with an early system at the author's nuclear physics laboratory serves as an example. The original computer and a similar machine later installed with it are now overloaded and a new system is under construction. The success of the interactive data analysis on the original system has made it desirable to enhance the display and light pen facilities while reducing the computer time involved in generating the displays. The use of a data storage/display disc effectively provides off-line displays but requires more manipulation in data acquisition. The solution is found in the large number of processing units economically feasible with third-generation equipment. Two linked computers will perform data acquisition and analysis, the smaller performing data acquisition under the control of the larger, which will run a fairly simple time-sharing system. Together with several I/O processors, this hierarchy of processors will provide ease of program development and a very high degree of computational power and data acquisition capability.

Measuring Optical Transfer Functions of Lenses with the Aid of a Digital Computer *by J. B. Davis and H. H. Herd, p. 93.* The problems involved in lens testing, as opposed to the testing of one lens under one set of conditions, are of sufficient magnitude and complexity that the use of a computer is almost imperative to make the job practical. A machine and method for evaluation of lenses is described which employs a digital computer as a major component, has no restrictions as to the quality of lenses which may be accommodated, and requires no precision targets or auxiliary optics of any type. The results are in a form directly applicable to predictions of performance of complicated systems where the lens is one of several linear dissipators.

The reader is introduced to lens testing considerations and a brief discussion of methods, followed by a detailed description of a specific implementation and computerized approach. Next, the basic mathematics involved, including a practical procedure for truncating a Fourier series, are explained in some detail. Finally, examples of measured output and machine accuracy and stability examination are given.

The Use of Computers at CERN *by R. T. Bell and H. Øverås, p. 104.* This paper surveys the many ways computers

and connected special devices are used in the laboratory of high energy nuclear physics research of CERN (European Organization for Nuclear Research) in Geneva, Switzerland.

An Experimental System for Time-shared, On-line Data Acquisition *by H. A. Reich, p. 114.* With the increasing availability of terminal-oriented, time-shared computers, it now becomes feasible to extend the method of use to include real-time, on-line data acquisition and data reduction. Here described is a particular embodiment of such a system, using an IBM 1050 terminal and the IBM Research M44/44X and the APL/360 Model 50 computers. Reasons leading to the choice of equipment, special devices, programming considerations, data rates and some economic factors are considered.

Real-time Reduction of Nuclear Physics Data *by P. R. Bevington, p. 119.* Small scientific computers have been widely used in research laboratories for on-line data acquisition to improve the efficiency of data collection and to perform sophisticated data manipulation before storage. An equally productive use of such computers is for the subsequent reduction of these data in real time, permitting interaction between investigator and computer and providing immediate interpretation of masses of data. This report describes the philosophy and techniques developed for the SCANS (Stanford Computers for the Analysis of Nuclear Structure) system for the reduction in real time of multichannel pulse-height spectra, which comprise the bulk of data in Nuclear Physics. The programming language for users is FORTRAN, to provide flexibility and ease in introducing and modifying sophisticated concepts such as nonlinear least-squares fitting. Software interface to specific real-time hardware devices such as oscilloscope display and light pen is accomplished via library subroutines which perform a variety of general purpose services. Several different applications of this approach to various types of data spectra are discussed to illustrate the degree of mutual interaction achieved between investigator and computer and the resultant optimization of reduction techniques to suit particular types of data.

The Use of a Control Computer in a Chemistry Department *by Y. Okaya, p. 126.* The Chemistry Department of the Stony Brook Campus of the State University of New York is composed of a number of faculty members whose research experiments fall generally into two categories; (1) steady data acquisition and control tasks with relatively small data and demand rates, and (2) continuous scan-type measurements of various data rates. An IBM 1800 control system is employed as the nerve center of a computer-based experiment complex.

This paper discusses the multi-experiment control system used at Stony Brook Chemistry, giving some details of experiments performed by faculty members as examples of its application. It is pointed out that one of the objectives of this computerized department is creation of a course in the use of computers in chemistry. With a data-acquisition computer available in the department, the course can include actual bench practice in data acquisition and control tasks.

Use of a Terminal System for Data Acquisition *by K. L. Konnerth, p. 132.* The application of a mathematically-oriented conversational computing system to data collection and computer control for a specific experiment is described. Relatively simple interfaces are used between the experiment and computer terminal to provide for voltage analog inputs and outputs to the experiment. The terminal is connected to the computer by way of conventional voice-grade telephone lines. It is concluded that this type of data acquisition system is quite useful for experiments in which several-second computer response time can be tolerated, data reduction is necessary and the computer load is insufficient to justify the use of a local computer. An additional facility which provides for the ability to plot data was found to be extremely useful.

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The Kinoform: A New Wavefront Reconstruction Device *by L. B. Lesem, P. M. Hirsch, and J. A. Jordan, Jr., p. 150.* A new, computer-generated, optical element called a kinoform is described. This device operates only on the phase of an incident wave and forms a single image by wavefront reconstruction without the unwanted diffraction orders characteristic of holograms. The kinoform is also more efficient in the use of spatial frequency potential and reconstruction energy and can be synthesized in considerably less computer time than the digital hologram.

Associative Holographic Memories *by D. Gabor, p. 156.* Recently Longuet-Higgins modeled a temporal analogue of the property of holograms that allows a complete image to be constructed from only a portion of the hologram. In the present paper a more general analogue is discussed and two two-step transformations that imitate the recording-reconstruction sequence in holography are presented. The first transformation models the recall of an entire sequence from a fragment while the second is more like human memory in that it provides recall of only the part of the sequence that follows the keying fragment. Both models require only the three operations: shift, multiplication and addition.

Computer-generated Binary Holograms *by B. R. Brown and A. W. Lohmann, p. 160.* Holograms synthesized by computer are used for constructing optical wavefronts from numerically specified objects. Elimination of the need for a physical object has made new applications possible, for example, three-dimensional computer output displays, synthetic prototypes for interferometric testing, and filters for various optical data processing operations. Our computer holograms differ from a normal hologram in that the transmittance is

binary, yet they are able to construct general wavefronts and images efficiently and have several practical advantages over holograms with a continuous range of transmittance. Recent improvements that simplify the production of binary holograms and improve their performance are described and experimental work showing reconstruction of two- and three-dimensional images is presented.

Electron Beam Writing of Spatial Filters *by H. Wieder, R. V. Pole, and P. F. Heidrich, p. 169.* A method is described for the generation of optical spatial filters using electron beam-addressed crystals of KDP. Some examples of simple filters which have been successfully written by this method are presented.

Graphic Computer-assisted Design of Optical Filters *by F. Gracer and R. A. Myers, p. 172.* An interactive graphic system is described in which a designer using a light pen creates an optical filter design at an IBM 2250 Graphic Console controlled by an IBM 1130 computer. The designer can observe the reflectivity (or some other property) of the filter as a function of wave number plotted on the CRT. The application was developed using an experimental graphic version of the 1130 Continuous System Modeling Program (CSMP), a general purpose, block-oriented simulation language in which the functional blocks represent the elements and organization of an analog computer. The designer has available a full set of operators for further analyzing the behavior or modifying the design of the filter. In addition to providing a highly flexible analytic tool, the system is intended to explore means for making the interactive computer terminal an important element in the inventive process.

Switchable Total Internal Reflection Light Deflector *by M. E. Rabedeau, p. 179.* A new digital light deflector, capable of being switched in less than 35 μsec with less than 300 V, uses the principle of switchable total internal reflection. The deflector produces high-quality, high-contrast images and its low cost and high light transmittance make it potentially well suited for use in optical-beam-addressable memory systems as well as for other applications in which random deflection is desirable.

Efficiencies and Bandwidths of Intracavity Acousto-optic Devices *by E. G. Lean, M. L. Dakss, and C. G. Powell, p. 184.* Acousto-optic devices based on isotropic and anisotropic acoustic Bragg diffraction will be discussed in terms of their efficiency and bandwidth. The conflicting requirements on the width W of the acoustic column with regard to efficiency and bandwidth determine the basic limitations of the devices. A scheme using the acousto-optic devices within a flat-field conjugate (FFC) angularly degenerate laser cavity has been experimentally demonstrated. The bandwidth of the new scheme is limited by the field angle of the FFC cavity instead of by W^{-1}. The width W can be made as large as possible to increase the diffraction efficiency without decreasing the bandwidth. The new scheme provides means for high efficiency and large bandwidth in optical deflection and signal processing systems.

High Performance Reduction Lenses for Microelectronic Circuit Fabrication *by R. E. Tibbetts and J. S. Wilczynski, p. 192.* Data are presented for three families of objective lenses useful in making high resolution plates and improving the process of photoresist exposure. These lenses have 7 to 10 elements each, spherical surfaces only, and were designed with the aid of computers. Many of the lenses have been fabricated and these have confirmed the soundness of the design methods, assessment criteria, and manufacturing techniques.

Mechanisms of Stress Relief in Polycrystalline Films *by P. Chaudhari, p. 197.* The stress required to operate dislocation sources within a grain, at a grain boundary, and at surfaces is found to be larger than the intrinsic stresses observed in polycrystalline films. It is therefore unlikely that a dislocation flow mechanism can relieve stresses in films. Grain boundary sliding and diffusional creep can, however, relieve stresses in films and equations describing the kinetics of stress relaxation are derived. It is suggested that stress relief occurs primarily by a diffusion-creep mechanism. Growth of hillocks during annealing of a film is briefly discussed in terms of the diffusion-creep mechanism.

Effects of Bending Stiffness in Magnetic Tape *by R. E. Norwood, p. 205.* The elasticity of magnetic tape is an important factor in determining the shape of a tape loaded over a magnetic head. Over a single apex the radius of curvature of the tape is inversely proportional to the wrap angle and to the square root of the ratio of tape tension to bending stiffness. If a constant-pressure support is assumed instead of a knife edge, the radius of curvature increases considerably. A chart is provided for use in calculating the radius of curvature under different loading conditions.

Over a double apex the results are the same as for a single apex except when the distance between apexes becomes small. By increasing the radius of curvature of the head to conform to the radius of curvature of the tape, the rate of head wear can be greatly reduced.

Symbolic Polynomial Operations with APL *by A. J. Surkan, p. 209.* A recursive calculation of polynomial coefficients is used to demonstrate how functions performing polynomial algebra and differentiation may be written concisely in Iverson notation and executed by an on-line, time-sharing implementation of APL. These functions will operate on symbolic polynomials with constant coefficients and display in a superscripted format results having up to 116 variables.

On the Measurement of Impurity Atom Distributions by the Differential Capacitance Technique *by D. P. Kennedy and R. R. O'Brien, p. 212.*

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SLT Device Metallurgy and its Monolithic Extension *by P. A. Totta and R. P. Sopher, p. 226.* The glass-passivated, face-down semiconductor chip joining technology employed in IBM's SLT (Solid Logic Technology), has become not only a fundamental element in the hybrid circuitry of System/360 but also the basis for later metallurgical designs. The "flip-chip," copper ball terminal, solder reflow technique is comprehensively reviewed and a discussion is given of its extension, through the use of ductile, all-solder terminals, to monolithic applications.

Controlled Collapse Reflow Chip Joining *by L. F. Miller, p. 239.* Solder reflow connection of semiconductor devices to substrates has been shown to be a reliable, effective, and readily automated technique. Rigid copper spheres, which remain rigid during solder reflow, have been used successfully for some time as a major element of the contact joint. However, to expand the capability of such joints to larger devices such as multiple-transistor chips in hybrid components, ductile metallic joining pads can be used on the devices instead of the copper spheres to reduce mechanical strains and permit multi-pad devices to make proper contact to module lands during reflow. This paper describes a technique that prevents these solder pads from collapsing and permits large scale production. Termed "controlled collapse," the method is based on limiting the solderable area of the substrate lands and chip contact terminals so that surface tension in the molten pad and land solder supports the device until the joint solidifies. The result is a sturdy, testable connection of high reliability (bond strength 30-50 gm, pilot-production yields exceeding 97%, predicted failure rate—based on laboratory tests—considerably lower than that of copper ball contacts). The process is economically adaptable to automation and offers considerable latitude in fabrication and control tolerances.

Geometric Optimization of Controlled Collapse Interconnections *by L. S. Goldmann, p. 251.* This paper deals with the mechanical reliability of controlled collapse solder joints in modules subjected to the thermal fatigue conditions of machine usage. Particular emphasis is placed on design variability and how the shape and dimensions of the joint and chip affect reliability. A systematic technique is presented to optimize pad dimensions. A new experimental method to characterize chip-to-substrate interconnections—the torque test—is described and analyzed. Its applicability to design evaluation is discussed and representative data are analyzed. The relationship between torque test measurements and fatigue is discussed.

Reliability of Controlled Collapse Interconnections *by K. C. Norris and A. H. Landzberg, p. 266.* The use of solder pads to join multi-pad integrated circuit chips to modules provides a highly reliable, rugged interconnection technology. This paper reports some important aspects of the reliability evaluation that was carried out on the "controlled chip collapse" interconnection system developed by IBM. Included are an analysis of the mechanics of the system, a model to establish the relationship among different thermal fatigue testing conditions, and experimental verification of the model. In the course of this work, the chip failure rate of the interconnection as used in present designs was predicted to be better than 10^{-7}%/1000 hours for the mechanism studied.

Parametric Study of Temperature Profiles in Chips Joined by Controlled Collapse Techniques *by S. Oktay, p. 272.* Parameters governing the temperature profiles of typical semiconductor chips joined to circuit module substrates by controlled chip collapse (flip-chip bonding) techniques are discussed. These include the physical and geometric properties of various layers of metals and non-metals that form the chip-to-substrate interconnection. The importance of the bond between the interconnection and the substrate from the point of view of interfacial thermal resistance is indicated. Also, the "thermal pinch" effects of voids in controlled chip collapse interconnections are discussed. The various thermal impedances as obtained from computer simulated temperature profiles are given graphically as functions of the parameters. The derivation of a semi-empirical expression for predicting the transient response of junctions on joined chips is shown.

Studies of the SLT Chip Terminal Metallurgy *by B. S. Berry and I. Ames, p. 286.* The thin film metallurgy used for SLT chip terminal contacts has been studied with respect to the soldering procedure used for chip-to-module joining. A simple solder immersion test was used to study wetting and dewetting effects on Cr films overlaid with films of Cu and other metals. It was found that the initial soldering reaction (consisting of the conversion of the Cu film to a Cu-Sn metallic layer) proceeds to completion in only a few seconds. Thereafter, the intermetallic layer starts to disintegrate and become thinner by a mechanism identified as solution-assisted spalling. Removal of the intermetallic layer by this mechanism is not limited by simple solubility considerations. From metallographic observations and the inability to produce direct wetting of Cr films by solder, it was concluded that the basic cause of solder dewetting is the excessive loss of intermetallic from the underlying Cr film. Dewetting is accelerated if the Cu film is deposited on an oxidized Cr surface. These observations underscore the importance of the manufacturing practice of overlapping the Cr and Cu depositions so as to obtain an adherent and interlocked structure which is resistant to spalling. Other studies have show that Al films are relatively inert to molten pure Pb-5% Sn solder, but are susceptible to rapid attack if gold is added to the solder. Appreciable delay of such attack is afforded by an overlying film of Cr, provided both surface and edge coverage are achieved.

Parallel Methods for Approximating the Root of a Function *by W. L. Miranker, p. 297.* We present a class of

methods for approximating the root of a function. The methods are designed for execution on a parallel processor and when they are so executed, the speed of the approximation process is increased. The increase in speed is estimated analytically by computations of the order of convergence of the various methods presented.

Scattering of Electromagnetic Radiation by a Large, Absorbing Sphere *by J. V. Dave, p. 302.* Details are provided for two subroutines with which one can compute the various characteristics of the electromagnetic radiation scattered by an absorbing, homogeneous sphere of any reasonable size. The necessary expressions for this purpose were first derived by Mie. The method of computations used is the so-called method of logarithmic derivative of one of the complex functions, introduced by Infeld. The main difference between the two subroutines is in the procedure used in computations of one of the functions. This function is computed by an upward recurrence procedure in one subroutine and by a downward recurrence procedure in the other.

Sufficient results for demonstrating the reliability of these programs are presented and discussed for a sphere of 10μm radius illuminated by an unpolarized radiation of 0.4μm wavelength.

A General Method for Obtaining Impedance and Coupling Characteristics of Practical Microstrip and Triplate Transmission Line Configurations *by Y. M. Hill, N. O. Reckord, and D. R. Winner, p. 314.* In order to design an interconnection system for nanosecond-risetime logic circuitry, it is necessary to obtain a balance between impedance variations, propagation velocities, and crosstalk levels so as to achieve the best system speed as well as system speed control. To accomplish this, it is necessary to relate the electrical material properties and physical dimensions of the connections to characteristic impedances, propagation velocities, and crosstalk coupling coefficients.

Two practical transmission line configurations: the microstrip line, which is coated for physical protection, and the offset or unsymmetrical triplate line, are being fabricated by mass production techniques. Because of the close control required and the many factors affecting impedance and coupling, these configurations require accurate means for predicting their characteristics.

An improved "subintervals" technique and a series approximating the Green's function have been combined to yield a single practical computer algorithm. Excellent agreement has been obtained in comparing the results of computations with large scale-model transmission line measurements. The method is quite general because dimensions, conductor shapes, and dielectric properties may vary widely.

Thermal Expansion in a Constrained Elastic Cylinder *by J. F. Janak, p. 323.* The stress developed in an elastic cylinder of finite length undergoing thermal expansion with one end clamped is expressed in terms of a series expansion of a biharmonic function, appropriate derivatives of which give the displacements and stresses within the cylinder. The coefficients in this series are determined by a least-squares fit to the boundary conditions at the ends of the cylinder and values of the stress on various surfaces are found as functions of the height-to-radius ratio. All components of the stress tensor become infinite at the circumference on the clamped end. A tabulation is included of quantities of interest in any cylindrical problem in which the curved surface is a free surface.

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Stochastic Model for Manufacturing Cost Estimating *by C. T. Abraham and R. D. Prasad, p. 343.* The unit manufacturing cost (i.e., its estimator) for a given manufacturing program with stochastic demand and operation yield is assumed to be a random variable. For a simple series production line the probability distribution of the unit manufacturing cost has been derived by either the transform method, which uses Mellin and Laplace transforms, or the method of moments, which uses either the Gram-Charlier series approximation or the Pearson system of frequency curves. The estimates and 90%-confidence intervals for the base manufacturing cost are computed for two device-component products. The model cost estimates are very close to the actual values and the confidence intervals are sufficiently narrow to be useful in applying contingencies to the predictions.

Dynamic Inventory Models and Stochastic Programming *by M. N. El Agizy, p. 351.* A wide class of single-product, dynamic inventory problems with convex cost functions and a finite horizon is investigated as a stochastic programming problem. When demands have finite discrete distribution functions, we show that the problem can be substantially reduced in size to a linear program with upper-bounded variables. Moreover, we show that the reduced problem has a network representation; thus network flow theory can be used for solving this class of problems. A consequence of this result is that, if we are dealing with an indivisible commodity, an integer solution of the dynamic inventory problem exists. This approach can be computationally attractive if the demands in different periods are correlated or if ordering cost is a function of demand.

Programmed Automatic Customer Engineer (PACE) Dispatch *by W. H. Evers and S. S. Thakur, p. 357.* An experimental real-time system is described for assigning customer engineers (servicemen) to requests for service, preventive maintenance and engineering- and sales-change activities. The system, which can be applied to service organizations of many kinds, is viewed as a stochastic

programming formulation. The resultant mathematical programming problem is structured as a control system, an inner control loop and an outer adaptive feedback loop in which system parameters are adjusted based on a performance index. Tests of the system have been made using data from the Brooklyn, New York and Washington, D.C. IBM Field Engineering Division branch offices.

Model of Competition in a Two-seller Market *by D. Savir, p. 366.* In this model of sellers' competition we are concerned with the transition from a single-seller market to a two-seller market, the effects of transition on the first seller, his likely reactions and the thereby changed market situation that awaits the entering competitor. The decision variables considered in this model are the sizes of the two sales forces. We show that the enterer should not view the market as it stands prior to his entry, but as changed by the first seller to accommodate or oppose his entry. Upon the entrance of the competitor, both sellers must increase their sales forces to attain the levels of profit anticipated prior to entry, if indeed these can be attained. Equilibrium strategies are shown to be maximal sales effort on the part of the first seller and either maximal sales effort or abstention from entry on the part of the enterer. A finite series is derived to express the exact expectation of a class of rational functions of a binomially distributed random variable.

Maximal Biflow in an Undirected Network *by J.-C. Arinal, p. 373.* In this network flow problem we deal with two distinct commodities, each commodity being identified by a pair of source and sink nodes. The problem consists of maximizing the total flow (biflow) of the two commodities. It is solved by an inductive algorithm which starts with a maximal multiterminal flow from the set of sources to the set of sinks in the network, yields the value of the maximal biflow and terminates with the construction of the maximal biflow itself. Computational experience shows that this algorithm can also be used in the three-commodity flow problem to obtain a good lower bound for the value of a maximal three-commodity flow.

Algorithm and Average-value Bounds for Assignment Problems *by W. E. Donath, p. 380.* A new suboptimal intermediate-speed algorithm which uses $n^2 \ln n$ steps is developed for the assignment problem. Upper and lower bounds are derived, using this algorithm and other methods, for the average values of three classes of $n \times n$ assignment problems:

1. When the elements of the matrix are random numbers uniformly distributed over the range 0 to 1, the average optimal value is smaller than 2.37 and larger then 1 for problems with large n. Experimentally the value is about 1.6.
2. When the elements of the matrix are random numbers such that the probability of being less than x is $x^{k+1} (k \neq 0)$, asymptotic expressions for the upper and lower bounds of the average optimal value are $C_l n^{k/(k+1)}$ and $C_l[(k+1)/k] n^{k/(k+1)}$, respectively.
3. When each column of the matrix is a random permutation of the integers 1 to n, asymptotic upper and lower bounds are $2.37n$ and $1.54n$, respectively. Experimentally the value is about $1.8n$.

Shortcut in the Decomposition Algorithm for Shortest Paths in a Network *by T. C. Hu and W. T. Torres, p. 387.* The problem considered is that of finding the shortest path between the two nodes of every pair in a large n-node network. A decomposition algorithm is proposed for use when the number of arcs is less than $n(n-1)$. The network is first decomposed into several overlapping subnetworks. Next, with each subnetwork treated separately, conditional shortest paths are obtained using triple operations. Finally, these conditional shortest paths are used to obtain the shortest paths between paired nodes in the original network by matrix mini-summation. This decomposition algorithm requires less computer storage and fewer arithmetic operations than other known algorithms.

Minimaximal Paths in Disjunctive Graphs by Direct Search *by J.-F. Raimond, p. 391.* The problem of finding a minimaximal path in a disjunctive network is stated in terms of both graph theory and linear programming with mixed-integer variables. It is solved in both formulations using a "direct search" scheme with additional dynamic features, which seems to be a more efficient algorithm than those based on other methods. Although it yields an optimal solution, the algorithm can be used as such or with very few changes to find suboptimal solutions for larger problems. Computational experience on the general machine scheduling problem is described.

Heuristic Algorithm for the Traveling-salesman Problem *by T. C. Raymond, p. 400.* The classical traveling-salesman problem is to determine a tour that will minimize the total distance or cost involved in visiting several cities and returning to the starting point. This paper describes a new heuristic algorithm that has been programmed for a digital computer and that obtains optimal or near-optimal solutions to the problem. The author's general approach was derived from an existing algorithm developed by Karg and Thompson in 1964. Computational results for five multi-city tours are presented and the algorithm is shown to be competitive with other existing heuristic techniques.

IBM 2750 Voice and Data Switching System: Organization and Functions *by B. Corby, p. 408.* This paper reviews the functions of private automatic branch exchanges (PABX's) and describes the organization of the IBM 2750 Voice and Data Switching System. This system has two main functional areas: (1) line switching, transmission and signaling, and (2) common control. The switching network uses a new integrated electronic crosspoint. The common

control is performed by a built-in duplexed computer with stored programs dedicated to line switching.

The IBM 2750 offers a variety of normal and advanced voice features, and some entirely new data features, and is designed for interconnection with an IBM System/360. Four companion papers describe the electronic switching network, the network control program, and the integrated crosspoint in greater detail.

Electronic Switching Network of the IBM 2750 *by R. E. Reynier, p. 416.* A description of the voice and data switching network of a fully electronic private automatic branch exchange (PABX) is given, including a description of the crosspoint device and its principles of operation. Some related circuitry is described, including the terminal and service circuits, supervision circuits and a loss-compensation device.

Operational Program for the IBM 2750 *by J.-D. Colas, p. 428.* This paper describes the operational program of the IBM 2750 Voice and Data Switching System. The program runs in the supervisor unit of the two network controllers used in the 2750. This program controls: (1) the duplexing of the network controllers; (2) the switching network; (3) the data collection and transmission operations passing through the system, including interconnection with IBM System/360; (4) the on-line error handling and system testing.

The IBM program uses all available core storage. It is flexible, is tailor-made to each customer's requirements, and runs continuously without customer assistance.

Semiconductor Crosspoints *by L. L. Rosier, C. Turrel, and W. K. Liebmann, p. 439.* The design considerations for a semiconductor crosspoint consisting of an SCR-diode-resistor circuit are presented and the fabrication process is briefly reviewed. These crosspoints have an ON-resistance of three to four ohms and a capacitance of approximately three picofarads. They can be interconnected on ceramic modules to form matrix arrays for use in telephone line switching applications.

Response Time of Thyristors: Theoretical Study and Application to Electronic Switching Networks *by E. Y. Rocher and R. E. Reynier, p. 447.* After restating the experimental definition of the response time of a low-power thyristor by assuming a well-defined dc triggering current, the authors show that the equivalent two-transistor representation of the thyristor leads to a theoretical interpretation of the triggering condition under certain simplifying assumptions. The accuracy of this theoretical model is shown to be satisfactory.

A practical definition of the response time of a thyristor is proposed, and the literal expression of the response time as a function of the parameters of both constituent transistors is given. Examples of application are then given in the design of the switching networks of the IBM 2750, where thousands of thyristors are used as crosspoints arranged in matrices and connected in series.

Data Recovery in a Photo-Digital Storage System *by R. L. Griffith, p. 456.* A data-recovery feature has been developed for recovering electron-beam recorded information which is microscopic in dimension and has been partially obliterated by flaws in a photographic-film recording medium. This feature provides (1) backup procedures that exploit redundancies in the recording format for the synchronization and identification of data, (2) coding for error detection and correction of 5 independent characters in 50 data character lines, (3) variation of machine parameters that affect reading performance, and (4) statistically optimized schedules for applying a variety of recovery techniques. Error rate is reduced from one error line in about 100 lines to less than one error line in 2.7×10^6 lines.

Modeling Plasma Effects on Radar Cross Section of Reentry Vehicles *by F. H. Mitchell, Jr., W. R. Mahaffey, and R. F. Jacob, p. 468.* In order to design a radar to detect, track, and identify unknown targets, models of the expected electromagnetic scattering properties of the targets must be developed. This communication begins with a qualitative discussion of interactions between an incident wave and a plasma-clad body in order to give the general reader a heuristic understanding of the problem background. Then rigorous calculations of normalized backscatter cross section for a spherical, plasma-clad body, and the limitations of this model, are presented in context with earlier background material.

A plasma simulation technique is described as a means for modeling a diverse range of reentry bodies and plasmas that are not amenable to analytic solution. The theoretical analysis can be used to validate the simulation technique in a spherical configuration after which the technique can be used to simulate many other plasma shapes around a variety of bodies.

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A Perspective on Acoustoelectric Instabilities *by R. Bray, p. 487.* The acoustoelectric instabilities appear in diverse forms and seem complex because of the large number of factors which influence them. A perspective on the instabilities is provided in terms of experiments on the III-V semiconductors, selected to limit or control the variables. Detailed evidence is presented that the source of the acoustic flux is the thermal equilibrium phonon spectrum. The individual contributions of various factors to the instabilities are identified and discussed; e.g., 1) circuit conditions (constant current or constant voltage) which determine the degree of feedback between buildup of flux and gain everywhere in the sample, 2) boundary conditions, including destruction or reflection of flux, 3) inhomogeneities in resistivity of the samples, to which the current oscillations and

initial stages of domain formation are particularly sensitive, and 4) the form of the acoustoelectric gain curve, which determines whether the feedback on the gain is positive or negative when the current is changed by the flux buildup. Also, several aspects of deviation from small signal theory are identified. In strong flux, 1) the peak of the frequency spectrum of the flux is shifted down, 2) the acoustoelectric gain coefficient is changed, and 3) the carrier distribution function may become hot in the high field of the domain. It is concluded that the strong flux effects modify but do not basically determine the form of the resistance instabilities.

Parametric Amplification and Frequency Shifts in the Acoustoelectric Effect *by S. Zemon and J. Zucker, p. 494.* Mechanisms for the downshift in the frequency of maximum acoustic intensity f_{mi} for high flux domains in piezoelectric semiconductors are reviewed. For the simple case where an externally introduced acoustic wave (pump) produces a single-frequency domain in photoconducting CdS, clear evidence is given that the downshift in f_{mi} is due to parametric amplification of thermal acoustic noise. For a pump of 990 MHz, after some initial growth ($v_d = 1.14\, v_s$), the pump is found to be depleted. In the pump depletion region, signals in a 200 MHz band about the even subharmonic (445 MHz) are found to grow. At pump strains of about 10^{-6} the signals propagated at angles to the pump equal to those that give phase matching according to the dispersion of linear theory. For higher pump strains, however, the collinear process is dominant. The signal domain is narrower than the pump domain, as expected, because the parametric growth is exponentially dependent on pump strain. The downshifting of f_{mi} in the region where deviations from linear theory are still small is discussed in terms of a parametric interaction model, with the initial acoustic strain distribution considered as an incoherent pump.

A Brillouin Scattering Study of Acoustoelectric Domain Formation in *n*-GaAs *by D. L. Spears, p. 499.* Brillouin scattering measurements in *n*-GaAs show (1) that the initial formation of acoustoelectric domains is the consequence of spatially inhomogeneous amplification produced by resistivity inhomogeneities, and (2) that the subsequent stages of domain evolution involve flux-dependent processes which further shape the domain; an important process appears to be parametric frequency conversion.

Off-axis Acoustoelectric Domains in CdS *by A. R. Moore, R. W. Smith, and P. Worcester, p. 503.* In CdS crystals oriented with the electric drift field parallel to the *c* axis, acoustoelectric domains consist of off-axis shear waves. This is because there is no acoustoelectric gain for shear waves traveling along the hexagonal axis, while the gain may be large in an off-axis direction. The particular angle at which the gain is a maximum depends on the angular dependence of the electromechanical coupling coefficient and the component of the electron drift velocity along that angle. These factors combine to make the angle of maximum gain a function of drift velocity along the *c* axis. Using a stroboscopic strain-birefringent method, we observed the off-axis domains directly. The domain tilt angle has been found to depend on drift velocity in roughly the same way as predicted from the small-signal angular dependence theory. Discrepancies may be the result of large-signal effects or of angular dispersion.

Acoustoelectric Amplification in InSb *by R. K. Route and G. S. Kino, p. 507.* It was demonstrated by Kikuchi that two modes of acoustoelectric domain oscillation occur in InSb in a transverse magnetic field. Using lithium niobate transducers on an acoustic amplifier, we have measured linear acoustic gain as a function of electric and magnetic field and frequency. At high magnetic fields ($B \geq 3000$ gauss) the results are in good agreement with White's theory. However, at low magnetic fields, the wavelength of the sound waves is less than the mean free path of the electrons, and the macroscopic theories break down. We have extended a microscopic theory of magnetacoustic interactions, due to Spector, to include electron drift. We find excellent agreement between theory and experiment over the whole range of magnetic field. Moreover, the results account very clearly for the two modes of acoustic domain formation.

Characteristics of Semiconducting Glass Switching/Memory Diodes *by A. D. Pearson, p. 510.* Semiconducting glass diodes can exhibit at least three conducting states: a high-resistance, or "off" state; a low-resistance, or "on" state; and a negative resistance state. When appropriately pulsed they can also display a memory function. The laboratory operation of simple diodes and the methods of inducing transitions among the various states are described. In addition, the possible role of phase changes in the mechanism of device operation is discussed, and new evidence in support of a filamentary conduction hypothesis is presented.

Physics of Instabilities in Amorphous Semiconductors *by H. Fritzsche, p. 515.* A four-fold classification of the current-controlled instabilities in amorphous semiconductors is proposed. The experimental evidence supporting a simple band model for the amorphous covalent alloys is given. The present understanding of the reversible switching effects and of the switching with memory is discussed.

Current Filaments in Semiconductors *by A. M. Barnett, p. 522.* A current filament is a non-uniform radial distribution of current in the presence of a uniform electric field in a uniform sample. These filaments can have diameters in the 0.005 inch range. The current density at the center of the filament can be several orders of magnitude higher than the background current density in the rest of the sample. Filaments have been studied in devices exhibiting the current-controlled negative resistance associated with specific cases of two-carrier space-charge-limited current double injection. Electrons and holes are injected from opposite

contacts into a semi-insulator in which the lifetime of carriers of one sign is much longer than the lifetime of carriers of the opposite sign. When forward biased this device exhibits a high-voltage, high-impedance (10^8 ohms) pre-breakdown region and a low-voltage, low-impedance (1 to 10^3 ohms) post-breakdown region. In the post-breakdown region current increases at a nearly constant voltage followed by a high-current power-law region. Current filaments have been studied throughout the post-breakdown region by recording the recombination radiation observed through one of the injecting contacts. Experimental and analytical studies of current filaments in silicon at 77K and GaAs at 300K are reviewed.

Current Oscillations in Deep-level Doped Semiconductors *by B. G. Streetman and N. Holonyak, Jr., p. 529.* We observe current oscillations in *p-i-n* (and optically excited *n-i-n*) devices containing deep levels. The oscillations occur in the positive resistance region of the space-charge-limited (SCL) current regime of the *I-V* characteristics, before the occurrence of double-injection breakdown. This is a general effect, occurring in Si, Ge, and GaAs compensated with various deep-level impurities and in electron-irradiated devices. The oscillations are sinusoidal at threshold, with frequency strongly dependent on the recombination kinetics of the *i*-region, and on the deep level density, but are essentially independent of device length. The frequency and amplitude of the oscillations are affected by temperature and optical excitation. Various models have been proposed to account for oscillations in semiconductors containing deep levels, but no existing model describes fully the various aspects of the effect reported here. Because the device length exceeds carrier diffusion length, any model for the oscillation mechanism must include the existence of space charge and the kinetics of recombination, but may not depend essentially upon a traveling domain which imposes a length dependence on the oscillation frequency. Tentatively, we favor a model in which the recombination process unbalances the steady or dc space charge.

Space-charge-limited Current Instabilities in n^+-π-n^+ Silicon Diodes *by A. K. Hagenlocher and W. T. Chen, p. 533.* If the strength of a pulsed electric field of about 10^3 volts/cm is exceeded in a nickel-doped 25,000 ohm-cm π-type silicon sample with n^+ contacts, a transient charge distribution is established that leads to a current instability. When the critical applied field is reached a current-controlled negative resistance is observed. The sample impedance decreases by several orders of magnitude, with a switching time in the nanosecond range, and microwave oscillations are produced. Below the threshold a space-charge-limited current flows, and voltage profile measurements show the presence of the expected negative space charge near the cathode. As the field is increased this space charge extends further into the sample. At the threshold the nickel centers become ionized, and a positive space charge is created in the center of the sample. This non-equilibrium distribution, which persists for a period of 200 to 300 microseconds, has properties similar to those of a gaseous plasma.

Time Response of the High-field Electron Distribution Function in GaAs *by H. D. Rees, p. 537.* Numerical calculations have been made of the high-field electron distribution function for GaAs, its small-signal frequency response and its behavior in large sinusoidal electric fields. The response speed is limited by the low scattering rate within the <000> valley. With increasing frequency the threshold field for negative conductivity rises and the negative mobility and oscillator efficiency fall. The free-electron dielectric constant is positive at high-fields, with a peak near the threshold field.

Negative Conductivity Effects and Related Phenomena in Germanium. Part I *by J. C. McGroddy, M. I. Nathan, and J. E. Smith, Jr., p. 543.* This paper is the first part of a two-part review of recent work on current instabilities and related properties of germanium in high electric fields. In this part we discuss the general subject of high field transport in *n*-Ge with emphasis on the concept of saturated drift velocity. The oscillations which result from bulk negative differential conductivity (BNDC) in [100] and [110] directions at low temperatures are discussed and related to the saturation effects. A discussion of theoretical and experimental evidence with regard to the BNDC effects is presented.

Finally, the anisotropy of the high-field conductivity is discussed and related to the Erlbach instability.

Negative Conductivity Effects and Related Phenomena in Germanium. Part II *by J. E. Smith, Jr., M. I. Nathan, and J. C. McGroddy, p. 554.* This paper is the second part of a two-part review of recent work on current instabilities and related properties of germanium in high electric fields. In this part the transferred carrier mechanism for producing bulk negative differential conductivity (BNDC) in a semiconductor is discussed. Experimental work on instabilities related to three realizations of this effect, in uniaxially compressed *n*- and *p*-type Ge, and in *n*-type Ge at low temperatures with field and current in a <111> direction, is reviewed. Theoretical understanding of these effects, which is largely qualitative at this time, is discussed. In an appendix a list of materials in which BNDC effects have been observed is presented, with some of the relevant properties of these materials.

Bulk Negative Differential Conductivity in Germanium: Theory *by E. G. S. Paige, p. 562.* Two mechanisms have been proposed for the bulk negative differential conductivity of *n*-type germanium first observed by Elliott et al. These are discussed with reference to recent Monte Carlo calculations in which effects due to intravalley acoustic phonon scattering, <100> and <000> minima and ellipsoidal constant energy surfaces are explored. Strong evidence is presented that electron transfer to <100> minima causes this negative

conductance. The origin of its temperature and orientation dependence is discussed.

Wave Propagation in Negative Differential Conductivity Media: n-Ge *by A. C. Baynham, p. 568.* A study has been made of transverse electromagnetic wave propagation in the negative differential resistance medium provided by suitably oriented *n*-type germanium at 77K. The wave frequency is chosen to fall below the critical scattering rates in this system (1 GHz), and the sample dimensions are maintained below the critical length for domain formation. Thus when the electric vector is oriented parallel to the dc biasing field, and the propagation vector is normal to the biasing field, growth of the wave is to be expected and evidence of it is presented. In addition, the real and imaginary parts of the conductivity are evaluated throughout the dc bias field range from zero to 3.5 kV/cm, for a range of resistivities.

Trap-controlled Field Instabilities in Photoconducting CdS Caused by Field-quenching *by K. W. Böer, p. 573.* The formation of stationary high-field domains adjacent to cathode or anode, dependent on the contact potential of the electrodes, their widening with increased applied voltage and their transition into two types of moving domains are discussed. Domains which move under deformation of the domain profile and usually dissolve before they reach the anode, and nearly undeformed moving domains are described. The structure and kinetics of these domains are directly observed using the Franz-Keldysh effect and photographs of typical domain forms are presented.

The Effects of Hydrostatic Pressure on Hot-electron Phenomena in n-InSb *by J. C. McGroddy, M. I. Nathan, W. Paul, S. Porowski, J. E. Smith, Jr., and W. P. Dumke, p. 580.* The effect of hydrostatic pressure on the Gunn effect (high pressures) and bulk avalanche breakdown (low pressures) in *n*-InSb is studied. The measured generation rates of electron-hole pairs at 77K and 195K at several pressures are compared with the theory of Dumke.

Location of the <111> Conduction Band Minima in the $Ga_xIn_{1-x}Sb$ Alloy System *by M. R. Lorenz, J. C. McGroddy, T. S. Plaskett, and S. Porowski, p. 583.* Pressure dependence of the resistivity and optical absorption by conduction band electrons are used to determine the position of the <111> (L_1) conduction bank minima in the $Ga_xIn_{1-x}Sb$ alloy system. These experimental data permit a more precise estimate of the position of the L_1 minima than had been possible using Gunn effect data alone.

The Influence of Boundary Conditions on Current Instabilities in GaAs *by M. P. Shaw, P. R. Solomon, and H. L. Grubin, p. 587.* We obtain excellent agreement among experiments eliciting a variety of GaAs current instabilities and the results of a computer simulation of GaAs with various fields imposed at the cathode boundary. When the cathode field is below around 4 kV/cm theory and experiments show that the *I-V* characteristics of the active element are linear up to about 3 kV/cm where the current saturates and no transit-time oscillations occur. Experimentally this element gives rise to severe noise in a resistive circuit and sometimes tunable oscillations in a resonant circuit. When the cathode field is in the differential negative resistivity regime the *I-V* characteristics of the active element are nearly linear up to a threshold field (determined by the *boundary* field) where current drop, voltage rise and transit-time oscillations occur. For cathode fields above about 15 kV/cm the *I-V* characteristics are nonlinear and the element exhibits tunable oscillations in a resonant circuit.

A Topological Theory of Domain Velocity in Semiconductors *by J. B. Gunn, p. 591.* A theory is given for the velocity of a free, steadily travelling domain of high electric field in a semiconductor exhibiting a negative differential conductivity. Explicit results are derived for the cases for which the domain behavior is dominated either by the (electric-field dependent) diffusion of electrons, or by the rate of transfer of electrons between states having different mobilities. It is shown that the solution for the electric-field distribution has the required properties only if the system of differential equations involved possesses singular points with special topological properties; this requirement serves to fix the domain velocity. The velocity depends only on the properties of the semiconductor at that high electric field where the effective drift velocity of electrons is equal to that outside the domain.

Avalanche Shock Fronts in p-n Junctions *by D. J. Bartelink and D. L. Scharfetter, p. 596.* The conditions necessary for the formation of avalanche shock fronts, narrow layers of avalanche moving through a diode depletion layer faster than the carrier saturated drift velocity, are shown to be related to the large-signal limits of Read and more general avalanche transit time diode theory. Analysis of shock fronts by a simple analytic method has been used to interpret computer simulations of high efficiency microwave oscillator diodes. The oscillation mode, called the Trapatt mode, involves a compensated electron-hole plasma that is trapped in the depletion layer for a portion of each cycle.

Coherent Microwave Emission from an Electron-hole Plasma *by B. B. Robinson and G. A. Swartz, p. 601.* Coherent microwave radiation, 6.5 to 44 GHz, is generated by InSb at 77K with an injected electron current transverse to a magnetic field. The maximum output power is about 10 microwatts for input power levels of one to five watts. Grooves cut into the Suhl surface of the rod-shaped InSb samples impose the coherence and determine the frequency range of coherent operation. Wavelength measurements of a surface wave show that the effective groove width is equal to about a half-wavelength. A theory of double-stream interaction in a thin plasma layer with a magnetic field transverse to the current flow predicts instabilities in the observed frequency range. The theory predicts all of the qualitative and several

of the quantitative features of the observed emission. Noise emission is predicted and observed at temperatures up to room temperature with appropriate onset magnetic fields. The theoretical analysis and concurrent experimental evidence demonstrate the existence of an instability in a thin-layer plasma in the absence of a magnetic field at 77K.

Negative Differential Mobility in Nonparabolic Bands *by G. Persky and D. J. Bartelink, p. 607.* A strong NDM (negative differential mobility) in *n*-InSb at low temperatures is predicted from a single non-parabolic band model. Calculations allowing for the anisotropy of the distribution function have been made using (1) a drifted Maxwellian, and (2) a "two-temperature" model. The calculated NDM threshold field of 550 V/cm is in an observable field range in *p-n* junctions. In bulk samples, where breakdown occurs at $E \approx 200$ V/cm, domain nucleation may take place at high-field inhomogeneities and contribute to the dynamics of the breakdown process and attendant microwave emission.

The Role of Acoustic Wave Amplification in the Emission of Microwave Noise from InSb *by C. W. Turner, p. 611.* The experimental evidence for the generation of microwave emission from InSb by acoustic amplification of thermal noise is reviewed. The conditions in which the electron-phonon interaction is likely to dominate over other possible physical mechanisms are discussed, with particular reference to crystallographic orientation and crystal geometry. The application of the small signal acoustic amplification theory is shown to lead to qualitative agreement between constant gain loci and emission threshold curves.

Noise Emission from InSb *by A. H. Thompson and G. S. Kino, p. 616.* This paper gives a new explanation of the low-field noise emission from InSb. Theoretical predictions and experimental measurements with a fine tungsten probe (10-μm definition) show that there are very large fields at one corner of the cathode contact in the presence of a transverse magnetic field. Our experiments show that avalanching occurs near this point and the noise amplitude has a strong maximum there. In a longitudinal magnetic field all samples measured have shown inhomogeneities near the cathode contact, which are the source of noise.

Microwave Emission and High-frequency Oscillations in *n*-Type InSb *by D. K. Ferry and W. A. Porter, p. 621.* Microwave emission from *n*-InSb at 77K in the presence of electric and magnetic fields was studied. Rectangular InSb samples were cut so that the long dimension and the applied electric field were parallel to one of the crystallographic axes <100>, <110>, or <111> and so that the position of all other axes was known. It was observed that instabilities in the voltage across the InSb sample accompanied the microwave emission and that, for a limited range of electric and magnetic fields, these instabilities were in the form of coherent oscillations. Both effects showed their lowest electric field thresholds when the magnetic field was parallel to one, but not a specific one, of the crystallographic axes. Both effects were shown to occur at electric fields below those expected for an electron-hole plasma and a close correspondence between the two effects was demonstrated.

Summary of Microwave Emission from InSb: Gross Features and Possible Explanations *by M. Glicksman, p. 626.* This paper reviews the experimental observations of microwave emission from InSb and the theories proposed to explain these. Two sources for some of the radiation, the acoustoelectric interaction and a collision-induced plasma instability, appear reasonably well established. Experiments are proposed to clarify a number of still unanswered questions.

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Energy Diagram Method for Bragg Reflections in Low Energy Electron Diffraction (LEED) Spectra *by P. M. Marcus, F. P. Jona, and D. W. Jepsen, p. 646.* A point of view and a method of calculation derived from energy band theory are applied to the problem of finding energies of Bragg reflections from a given crystal. Energy curves are defined and calculated which describe the behavior of individual diffracted electron beams for a given set of beams incident on a particular face of the crystal. Intersections of these curves correspond to and identify the Bragg reflections associated with each beam. Energy diagrams and Bragg peak positions are shown for simple cubic and face-centered cubic lattices for various angles of incidence. We discuss the method in some simple cases and then solve the problem of finding Bragg reflections from the general crystal lattice with an arbitrary surface plane and arbitrary incident beams. The effect of the surface in producing well-defined diffracted beams for any incident beam and in grouping the Bragg reflections into these beams is described. Tables and formulas, which apply to any direction of incidence, are given for the Bragg reflections from the (001), (110) and (111) faces of the face-centered cubic lattice.

Two-dimensional Mathematical Analysis of a Planar Type Junction Field-effect Transistor *by D. P. Kennedy and R. R. O'Brien, p. 662.* A two-dimensional mathematical analysis is presented of the steady-state mechanisms of operation within a planar type junction field-effect transistor (JFET). This analysis shows that the potential distribution within the source-drain channel follows from solutions of Poisson's equation rather than from Laplace's equation. In particular, velocity-limited carrier transport produces a region of carrier accumulation in a region of the source-drain channel previously assumed to be depleted of carriers by the gate junction space-charge layers. The results of this two-dimensional mathematical analysis are presented in graphic form.

Fast Sequential Decoding Algorithm Using a Stack *by F. Jelinek, p. 675.* In this paper a new sequential decoding algorithm is introduced that uses stack storage at the receiver.

It is much simpler to describe and analyze than the Fano algorithm, and is about six times faster than the latter at transmission rates equal to R_{comp}, the rate below which the average number of decoding steps is bounded by a constant. Practical problems connected with implementing the stack algorithm are discussed and a scheme is described that facilitates satisfactory performance even with limited stack storage capacity. Preliminary simulation results estimating the decoding effort and the needed stack size are presented.

RF Sputtered Strontium Titanate Films *by W. B. Pennebaker, p. 686.* Two deposition parameters are important in rf sputtering of $SrTiO_3$ films: the oxygen-argon content ratio, and the substrate temperature. More than 1% oxygen is needed to produce insulating films; the exact percentage required depends on system cleanliness. Both dielectric constant and crystallite size increase with increasing substrate temperature.

Films of 2400 Å deposited at 500°C on gold have a dielectric constant of 200. The dc conductivity closely follows the Poole-Frenkel model. Two dielectric loss peaks are believed to be caused in part by an oxygen deficient region near one electrode. The variation in the dielectric constant κ with electric field is similar to that observed in bulk material.

Cation Deficiencies in RF Sputtered Gadolinium Iron Garnet Films *by E. Sawatzky and E. Kay, p. 696.* RF sputtering of stoichiometric, polycrystalline gadolinium iron garnet material results in films significantly deficient in iron content. The cation deficiency is shown to be quite sensitive to preparatory conditions and reflects itself markedly in the magnetic and structural properties of the resultant films. Temperature dependent sticking probabilities and selective resputtering at the growing film surface are thought to be the most likely causes for the observed deficiencies. A simultaneously operated rf-dc two-target sputtering system is described in some detail, which allows an expeditious study of and subsequent compensation for the observed cation deficiency. Films with essentially the bulk garnet composition and bulk structural and magnetic properties were prepared in this two target system.

A Nonlinear Digital Filter for Industrial Measurements *by B. Pehrson, p. 703.* A simple algorithm is presented for nonlinear filtering of a time series composed of a gaussian component, pulses and steps. The method used is a combination of simple statistical techniques. The main advantage is claimed to be a scheme for adaptation of the filter parameters.

Strain and Temperature Distributions in a Thermally Activated Cantilever *by A. Sugerman, S. Schmidt, and Y.-O. Tu, p. 711.*

Mathematical Model for Pattern Verification *by R. C. Dixon and P. E. Boudreau, p. 717.* Pattern verification is mathematically defined, an appropriate decision function derived, and a measure for system evaluation is given. Two basic postulates are set forth to fully define a verification system: each known class is expected, with nonzero probability, to be verified under the correct class label; and the pattern vector extracted during verification should be descriptive of the given class, independent of which class label was entered into the system. Through appropriate use of a priori probabilities, three types of information can be incorporated into the theory: the expected number of times a given class will require verification, the expected use of each class label by a given class, and the likelihood that a particular class is susceptible to "impostor" patterns.

Optical Damage to $LiNbO_3$ from GaAs Laser Radiation *by E. P. Harris and M. L. Dakss, p. 722.* We have observed optical damage to $LiNbO_3$ at room temperature from focused cw GaAs laser radiation at a wavelength of 8450 Å. Visible damage was apparent after a 20-sec exposure corresponding to an energy flux of about 1.2×10^5 J/cm^2 and was observed by changes in the diffraction pattern of the crystal. This is believed to be the first report of such damage in the potentially useful wavelength range of 0.8 to 0.9 μm. No damage was observed at a wavelength of 9030 Å in a similar but pulsed-laser experiment.

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Dielectric Films for Ge Planar Devices *by T. O. Sedgwick, J. A. Aboaf, and S. Krongelb, p. 2.* A series of passivating and masking films was developed and evaluated for use in a Ge planar transistor technology. In the search for satisfactory films, silicon dioxide, aluminum oxide, silicon nitride and multilayer combinations of these films, as well as some doped and mixed-composition films, were studied. The films, formed by pyrolytic deposition or by sputtering, were evaluated and compared with respect to the following properties: etch rate; dopant masking; mechanical stress; oxygen, hydrogen and water permeability; stability with respect to elevated temperature electrical-bias stressing; and Ge-insulator interface electrical condition.

The most important results of our experiments are the following: Silicon nitride appears to be the only satisfactory mask for Ga diffusions, although silicon dioxide is adequate for As, P and Sb diffusion masking. The dielectric properties of pyrolytically deposited SiO_2 can be made to approach those of thermal SiO_2 by high temperature densification. The surface electrical properties of the Ge-SiO_2 interface are more stable to thermal annealing than is any other Ge-insulator combination. However, aluminum oxide has been shown to be much less permeable to oxygen, hydrogen and water vapor than is SiO_2. Since the Ge-insulator interface electrical properties are sensitive to these ambient gases, a satisfactory passivating film structure for Ge consists of an underlayer of SiO_2 and an overlayer of Al_2O_3, silicon nitride or other relatively impermeable film.

The Theory of Hot Electrons *by P. J. Price, p. 12.* This is a survey of methods of analysis of the hot-electron phenomenon in semiconductors. The earliest method depended on three basic assumptions: smallness of the deviation of $f(\mathrm{p})$, the carrier distribution function, from $f_0(E(\mathrm{p}))$, the distribution in energy E; the conventional relaxation-time relation between $f-f_0$ and df_0/dE; and smallness of df_0/dE. More general methods are associated with giving up, successively in the reverse order, these assumptions. Procedures for obtaining and solving equations involving f_0 only, based on a new approach due to Levinson, are developed. An inherently precise method for calculating f and related treatment of differential mobility, which requires computer implementation and which has recently come into use, is expounded. Test calculations for the case of n-germanium are reported.

On-line Far-infrared Michelson Interferometry in a Time-shared Mode *by J. N. Gayles, Jr., W. L. Honzik, and D. O. Wilson, p. 25.* A method is described for implementing real-time far-infrared Fourier spectroscopy in a time-shared environment. The system makes use of the IBM 1800 TSX-based General Experimental Monitor (GEM) and reduces by at least an order of magnitude the time between experiment initiation and the display of useful spectral frequency and intensity information. The key feature of the system includes conversational mode operation with the incomplete data array. This feature enables one to review at any interval the Fourier transform of the partially acquired data without in any way disturbing the process of data collection. Procedures are illustrated also for performing signal averaging and several comparatively routine spectroscopic tasks.

On the Equations of Holland in the Solution of Problems in Multicomponent Distillation *by D. S. Billingsley, p. 33.* Holland developed certain equations to be used to accelerate or induce convergence in multicomponent distillation calculations. In practice this procedure has been the most successful of any adjunct to the basic Thiele-Geddes or Lewis-Matheson procedure for solving these problems. It is of importance, therefore, to ascertain the conditions under which the Holland equations can be guaranteed to possess the required type of solution at each iteration. The types of specifications which fulfill these conditions are determined.

On the Maximum Likelihood Method of Identification *by T. Bohlin, p. 41.* The maximum likelihood principle of estimation applied to the linear black-box identification problem gives models with theoretically attractive properties. Also, the method has been applied to industrial data (various processes in paper production) and proved able to work in practice.

This paper presents further developments of the method in the case of a single output. The reliability and speed of the identification algorithm have been improved, and the method has been made easier to use. A rather sophisticated computer program, however, was needed. It employs a generalized model structure, an improved hill-climbing algorithm, and an automatic procedure for determining model orders and transport delays. Some statistics from performance tests of the program are presented.

Argon Content of SiO_2 Films Deposited by RF Sputtering in Argon *by G. C. Schwartz and R. E. Jones, p. 52.* When SiO_2 is deposited by sputtering in an argon rf glow discharge, the films so produced contain considerable amounts of trapped argon, as determined by x-ray fluorescence analysis. This argon content was measured as a function of various sputtering parameters: argon pressure, rf power, electrode spacing, substrate temperature, and magnetic field, the latter two being most influential. A simple theoretical model for the capture and release of argon is presented which explains an observed linear decrease of the argon concentration in SiO_2 with increasing temperature. Incorporation of argon into the sputtered SiO_2 film does not seem to impair the film's ability to act as a good passivating and insulating layer.

Superlattice and Negative Differential Conductivity in Semiconductors *by L. Esaki and R. Tsu, p. 61.* We consider a one-dimensional periodic potential, or "superlattice," in monocrystalline semiconductors formed by a periodic

variation of alloy composition or of impurity density introduced during epitaxial growth. If the period of a superlattice, of the order of 100 Å, is shorter than the electron mean free path, a series of narrow allowed and forbidden bands is expected due to the subdivision of the Brillouin zone into a series of minizones. If the scattering time of electrons meets a threshold condition, the combined effect of the narrow energy band and the narrow wave-vector zone makes it possible for electrons to be excited with moderate electric fields to an energy and momentum beyond an inflection point in the *E-k* relation; this results in a negative differential conductance in the direction of the superlattice. The study of superlattices and observations of quantum mechanical effects on a new physical scale may provide a valuable area of investigation in the field of semiconductors.

Calculation of the Current Density in the Contacts of a Thin Film Resistor *by J. Overmeyer, p. 66.* The two-dimensional boundary value problem appropriate to current flow in a film resistor is examined. A simple closed-form solution for current density into the contact is found to exist for the important case of a thin film resistor with extended lands. The spatial dependence of the current density into the contact is found to be similar to that obtained by Kennedy and Murley for the diffused resistor, with film thickness entering the functional dependence in a role analogous to the diffusion length of the dopant ion in the diffused resistor.

Indium-mercury Alloy as a Low-toxicity Liquid Electrode *by S. S. Russell and S. L. Levine, p. 70.*

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Dynamic Performance of Schottky-barrier Field-effect Transistors *by K. E. Drangeid and R. Sommerhalder, p. 82.* The dynamic performance of Schottky-barrier field-effect transistors is discussed, with the aim of finding in a most simple way the physical parameters on which the dynamic properties of a FET depend, how strong they influence the dynamic qualities of FET's, and what recommendations can be given as to proper choice of material or structure for FET's with good high-frequency performance.

Computer Aided Two-dimensional Analysis of the Junction Field-effect Transistor *by D. P. Kennedy and R. R. O'Brien, p. 95.* A two-dimensional analysis is presented of the mechanisms of operation for a junction field-effect transistor. Particular emphasis is placed upon the process of electric current saturation in both wide gate and narrow gate structures. It is shown that velocity saturated carrier transport in a source-drain channel produces heretofore unreported mechanisms of device operation. Comparisons made between the conclusions derived from this two-dimensional analysis and the conventional one-dimensional theory of JFET operation are presented in graphic form.

Projection Masking, Thin Photoresist Layers and Interference Effects *by S. Middelhoek, p. 117.* Projection masking is used for producing microwave semiconductor devices with micrometer or submicrometer structures. In contrast to contact masking, the mask is projected onto the silicon wafer by means of a high quality microscope objective. Since the chromatic errors of such a lens cannot be fully corrected, monochromatic light has to be employed. This, however, causes standing light waves to occur in the SiO_2 and photoresist layers, leading to unexpected effects. This report describes some of these effects and the experimental conditions under which satisfactory masking results can be obtained.

Microwave Properties of Schottky-barrier Field-effect Transistors *by P. Wolf, p. 125.* The microwave properties of silicon Schottky-barrier field-effect transistors (MESFET's) with a gate-length of one micrometer are investigated. The scattering parameters of the transistors have been measured from 0.1 GHz up to 12 GHz. From the measured data an equivalent circuit is established which consists of an intrinsic transistor and extrinsic elements. Some of the elements of the intrinsic transistor, notably the transconductance, are strongly influenced by the saturation of the drift velocity. Best performance of the intrinsic transistor is obtained with highly doped and thin channels. The measured power-gain is in good agreement with theoretical values deduced from the equivalent circuit. The best device has a maximum frequency of oscillation f_{max} of 12 GHz. The investigation reveals that the extrinsic elements, especially the resistance of the gate-metallization and the gate-pad parasitics, degrade the power-gain considerably. Without them a value of f_{max} close to 20 GHz is predicted.

Silicon and Silicon-dioxide Processing for High-frequency MESFET Preparation *by T. O. Mohr, p. 142.* Silicon wafer processing is described which provides submicrometer epitaxial layers on top of high-resistivity silicon substrates for fabrication of high-frequency metal-semiconductor field-effect transistors. Silicon-dioxide underetching at the border of an oxide window, performed in hydrogen at elevated temperatures, is one method of realizing 1-micrometer device structures.

Metallization Processes in Fabrication of Schottky-barrier FET's *by S. Middelhoek, p. 148.* The metallization processes necessary for the production of microwave Schottky-barrier field-effect transistors are described. Since the gate contact is only 1 micrometer wide, the holes and the metallization of the source, drain and gate contacts are produced simultaneously. Then in a subsequent process, the source and drain contacts are converted to ohmic contacts by the evaporation of Au-Sb onto these contacts. Mask alignment is not a problem because the Au-Sb spreads across the surface after suitable heat treatment.

Minimal Energy Dissipation in Logic *by R. W. Keyes and R. Landauer, p. 152.* Minimal energy dissipations for the logic process based on thermodynamics and general phase space considerations are known. The actual availability of these minimal dissipations has not, however, been demonstrated. These minimal dissipation sources in a computing system also act as noise sources and thereby lead to questions about the ultimate available reliability of the computing process. A new and hypothetical device is presented in this paper and used to construct a physically analyzable computing system. It is demonstrated that this system has dissipations larger than, but of the same order of magnitude as, the original minimal quantities. It is also shown that any required reliability can be obtained with this device, without increased energy expenditure, but at the expense of an increasing time per computational step.

Thermal Problems of the Pulsed Injection Laser *by R. W. Keyes, p. 158.* Heat is produced in short periods of time during pulsed operation of an injection laser. The temperature of the laser at the beginning of any pulse due to the heating caused by preceding pulses is calculated for several simple model cases. The results are applied in the description of performance deterioration caused by heating.

Application of RF Discharges to Sputtering *by H. R. Koenig and L. I. Maissel, p. 168.* The operation of rf discharges is described and the internal distribution of voltages is considered. The significance of this with respect to sputtering, particularly of insulators, is then discussed. An equivalent circuit for the discharge is presented and the influence of such parameters as pressure and magnetic field on the components of this circuit is described. Finally, energy distributions for positive ions, electrons, and negative ions incident at the substrate during deposition are given.

Control of RF Sputtered Film Properties Through Substrate Tuning *by J. S. Logan, p. 172.* A means has been found to control the rf potential of the substrate during rf sputtering. The application of this technique to the deposition of silica films has been investigated in detail. The technique can be described as the use of an adjustable rf impedance between the substrate holder and ground electrodes, which generates an rf potential by virtue of the flow of rf current through it. Adjustment of the rf potential of the substrate results in a controlled dc bias potential developed at the film surface, which correlates directly with the physical properties of the deposited films. In general, the most desirable film properties are obtained when the dc substrate bias (obtained by adjusting the substrate-holder rf impedance) is at a high negative potential. The effect of substrate bias on etch rate, pinhole breakup thickness, and argon content has been measured.

Re-emission of Sputtered SiO_2 During Growth and Its Relation to Film Quality *by L. I. Maissel, R. E. Jones, and C. L. Standley, p. 176.* An improved technique for measuring re-emission coefficients is described and data on the effect of temperature are presented. These are discussed in the light of a physical model of film growth during sputtering wherein constant re-emission of material throughout deposition occurs. Evidence is then presented that such re-emission is essential if films of high quality are to be obtained. To help assess "quality" in a quantitative fashion use has been made of the PBUT (pin-hole breakup thickness) phenomenon, which is described in some detail. The influence on PBUT of several system parameters such as sputtering pressure and impurity content is discussed and related to the re-emission coefficient.

Metal Edge Coverage and Control of Charge Accumulation in RF Sputtered Insulators *by J. S. Logan, F. S. Maddocks, and P. D. Davidse, p. 182.* The successful application of rf sputtered SiO_2 in the passivation of silicon semiconductor devices depends in part on the proper control of ionic charge migration in the insulator during sputtering, and on the adequate coverage of metal line edges by the insulator. It is shown that an appropriate combination of target purity, substrate temperature control and phosphosilicate blocking layer thickness can be used to achieve ionic charge densities at the silicon-SiO_2 interface of less than 1×10^{12} charges per square centimeter. The effects of argon ion bombardment are shown to be acceptably low for typical operating conditions. In a conventional system, the adequate coverage of metal line edges is shown to be influenced primarily by argon pressure and magnetic field. In a special system where the substrate potential can be varied, it has been shown that adequate edge coverage can be obtained at sufficiently negative potentials. These data are consistent with a mechanism requiring some resputtering to obtain the desired film coverage.

Automatic Impedance Matching System for RF Sputtering *by N. M. Mazza, p. 192.*

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Survey of the Field of Magnetic Semiconductors *by S. Methfessel, p. 207.* Magnetic semiconductors are materials with good band conductivity as well as magnetic order. Since each phenomenon requires a different description of the relevant electron states, the band structure of these materials is very complicated, containing band states as well as localized states. An important condition for strong interaction between the magnetic and the conducting electrons appears to be the existence of high densities of states at the Fermi energy, providing large carrier polarizations in the magnetized state.

Exchange Mechanisms in Europium Chalcogenides *by T. Kasuya, p. 214.* Superexchange mechanisms, which are mostly responsible for the nnn exchange constant I_2 in Eu chalcogenides, are investigated in detail. In contrast with the usual 3d transition metal compounds, the Kramers-Anderson mechanism is estimated to be one order of magnitude too small to explain the experimental results due to a small 4f →

2p transfer energy. The mechanism by which a p electron is transferred to a 5d state through the d-f exchange interaction gives the correct order of magnitude for I_2, with a negative sign, even though it is a sixth-order perturbation. The cross term between the above two mechanisms is shown to be nearly as important as the second mechanism and may have a positive sign. The indirect exchange mechanisms, in which the anion p level has no important role, are responsible for the nn exchange constant I_1. The phonon-assisted mechanism proposed by Smit is estimated to be more than one order of magnitude smaller than the experimental value. The d-f mixing term is proved to be responsible for I_1, in good agreement with experiment.

Long-range Magnetic Interactions (RKKY-type) in the UP-US Solid Solutions *by M. Kuznietz, p. 224.* UP, US, and the UP-US solid solutions have the NaCl-type structure and are good conductors of electricity. UP is anti-ferromagnetic of type I; US is ferromagnetic. Assuming U^{4+} cations, P^{3-} and S^{2-} anions, and RKKY interactions between the uranium localized 5f-electrons via the conduction electrons (≈1 in UP and ≈2 in US), the observed magnetic structures are accounted for, although these structures are also predicted by molecular field theory. A neutron diffraction study of the UP-US solid solutions has revealed two new magnetic structures, the type IA (2+, 2−) antiferromagnetic structure and the antiphase (5+, 4−) ferrimagnetic structure, which are of long range (several lattice parameters) and are typical of long-range RKKY-type interactions, as assumed in the simple model for these compounds. Further experimental evidence is given for the long-range magnetic interactions in uranium monopnictides and monochalcogenides and their solid solutions. The situation in these uranium compounds is compared with the corresponding lanthanide compounds, and the role of covalency and superexchange in the case of heavier anions is discussed.

Ordered Moment of NiS_2 *by J. M. Hastings and L. M. Corliss, p. 227.* The transition metal dichalcogenides exhibit a wide variety of both electrical and magnetic properties, from insulators to superconductors and from ferromagnetism through antiferromagnetism to diamagnetism. NiS_2 is a semiconductor with an anomalous paramagnetic behavior which leaves in doubt the existence of a local moment. Previous neutron diffraction data have failed to show any ordering down to 4.2K. Our neutron powder diffraction data on stoichiometric NiS_2 show a transition at 40K to a structure which can be described as ordering of the first kind. This is followed by an abrupt transition at 30K in which *additional* diffraction peaks appear and these are consistent with ordering of the second kind. Despite the fact that the powder data cannot indicate an unambiguous magnetic structure, the magnitude of the ordered moment can be fixed. The rms moments associated with ordering of the first and second kinds are 1.0 and 0.60 μ_B per nickel atom, respectively, and the total moment is 1.17 μ_B per nickel atom.

Specific Heat of SnTe-MnTe System from 2 to 25°K *by M. P. Mathur, D. W. Deis, C. K. Jones, A. Patterson, and W. J. Carr, Jr., p. 229.* The low-temperature specific heat of a series of semiconductor alloys of the SnTe-MnTe system, for Mn to Sn ratios of 0 to 0.1 has been measured in the temperature range 2 to 25K. Large anomalies are observed due, presumably, to the ordering of the Mn^{++} spin system. The temperature region over which these anomalies occur is roughly the region in which ferromagnetism is observed.

Localized and Itinerant Electrons in Oxides *by J. M. Honig, p. 232.* Recent work concerning the electrical properties of ReO_3, PrO_x, ($1.5 \leq x \leq 2.0$), TiO_2, $SrTiO_3$, perovskites, CrO_2, NiO, $Li_xZn_{1-x}V_2O_4$, V_2O_3, and Ti_2O_3 has been selectively reviewed in attempts to elucidate the conduction properties of the charge carriers. A number of controversial issues are pointed out: Frequently it is not known whether mobilities are activated or not, nor whether a given material should be classified as a polaronic or mixed-carrier material; neither is there agreement on the nature of electrical transitions. Discrepancies in electrical properties can generally be traced to insufficient control over preparation and characterization of samples.

Hall Mobility Measurements on Magnetite above and below the Electronic Ordering Temperature *by W. J. Siemons, p. 245.* Hall effect measurements were made on a single crystal of magnetite in the temperature range 65 to 373K. The Hall voltage was positive over the whole temperature range. The results can be explained by assuming that magnetite is a normal semiconductor below the transition point and a degenerate one above that temperature.

Transport Properties of Iron-nickel Ferrites *by P. Nicolau, I. Bunget, M. Rosenberg, and I. Belciu, p. 248.* The mechanism of electrical conduction in the magnetic semiconductors $Ni_xFe_{3-x}O_4$ with $0.6 < x \leq 1$ was investigated. The electrical properties of these compounds are extremely sensitive to the presence of α-Fe_2O_3 as a second phase. The exponential temperature dependence of the electrical resistivity ρ and the temperature-independent thermoelectric power θ are in good agreement with an electron-hopping model. The electrical conduction occurs by thermally activated electron hopping between octahedral Fe^{2+} and Fe^{3+} ions with an activation energy q. The values of ρ, q and θ depend on the Fe^{2+} concentration only, and are not sensitive to small deviations from stoichiometry due to the presence of cation or anion vacancies.

Metal-insulator Transition in Transition Metal Oxides *by T. M. Rice and D. B. McWhan, p. 251.* The metal-insulator transition in the V_2O_3 system is discussed. A recent series of experiments on V_2O_3 and $(V_{1-x}Cr_x)_2O_3$ is reviewed. The phase diagram for the system is described. The Cr-doped mixed oxides are insulating at room temperature for $x \geq 0.009$ and transform to a metal with the application of pressure. This phase transition is identified as a Mott transition. A

comparison is made between the experimental results and theoretical predictions of the Mott transition.

Magnetic and Electrical Properties of $(La_{1-x}Ca_x)MnO_3$ *by G. Matsumoto, p. 258.* Samples of polycrystalline $(La_{1-x}Ca_x)MnO_3$, where x takes values ranging from 0.005 to 0.3, have been studied experimentally. Specimens were carefully prepared in the stoichiometric forms by changing the oxygen partial pressure conditions for each value of x. For specimens having x smaller than 0.1, the Néel temperature T_N is almost constant, 141K, while the paramagnetic Curie temperature θ increases as x increases. On the other hand, for specimens in which x is greater than 0.1, both T_N (or T_c) and θ are almost equal and increase with the value of x. The Mn^{55} NMR spectra associated with Mn^{3+} and Mn^{4+} ions were observed in specimens having x smaller than 0.175, while motionally narrowed Mn^{55} spectra were observed where the values of x were 0.2 or 0.3. All the experimental results could be qualitatively explained by postulating that the d holes at the sites around Ca^{2+} ions contribute to both the electrical conduction and the magnetic interaction. The ferromagnetic interaction induced by mobile d holes can not be ascribed to the double-exchange interaction, if this interaction has the usual form $b \cos(\theta/2)$.

Band Structure of Magnetic Semiconductors *by D. Adler, p. 261.* The band structure of materials in which both localized and itinerant outer electrons are simultaneously present is discussed. The Franck-Condon Principle is applied, and small and large polaron formation is taken into account. A scheme for estimating the densities-of-states of perfect crystals and doped or non-stoichiometric crystals is suggested, based on the ionic many-body states as a starting point. Screening, covalency, crystalline-field and overlap effects are quantitatively considered. In particular, the band structures of both pure and Li-doped NiO are derived and found to be in agreement with the experimental observations. It is shown that conclusions which are based on ordinary donor and acceptor techniques fail to account for the effects of doping even in a qualitatively correct manner, due to the neglect of important correlation effects.

Transport Properties of the Europium Chalcogenides *by S. von Molnar, p. 269.* Transport properties of pure and doped Eu chalcogenides are reviewed to determine the mechanisms responsible for the anomalous behavior near T_c, the Curie temperature. It is found that, whereas the scattering theory of simple metals accounts for the behavior of materials containing impurities in excess of 2×10^{20} cm^{-3}, several models for transport have been proposed for smaller concentrations. The impurity hopping model appears to be consistent with the data for very dilute systems.

Temperature and Magnetic Field Dependence of the Conductivity of EuO *by M. R. Oliver, J. O. Dimmock, and T. B. Reed, p. 276.* The conductivity of EuO has been measured as a function of temperature from 30 to 300K in magnetic fields up to 50 kG. The zero-field resistivity exhibits a sharp elbow at about 50K, and increases as much as 10^8 between 50 and 70K to a broad maximum between 75 and 80K. In an applied magnetic field, the broad maximum is rapidly decreased and the elbow is shifted to higher temperatures. These data are interpreted in terms of a transfer of electrons between a conduction band and an electron trap. In the model the energy separation between the band and trap level depends on the magnetic energy of the crystal and is thus a strong function of temperature and magnetic field. At low temperatures the trap level is assumed to be above the conduction band edge such that the electrons lie in the band. As the temperature is increased the energy of the band edge increases such that it crosses the trap level at about 50K. The large increase in resistivity with increasing temperature and the effects due to the magnetic field are explained by the transfer of electrons from the energy band into the trap states.

Tunneling Spectroscopy in Ferromagnetic Semiconductors *by W. A. Thompson, F. Holtzberg, and S. von Molnar, p. 279.* The observation of zero-bias anomalies in tunneling has received much attention but their interpretation has suffered from a lack of definition of the character of the tunneling barrier. Junctions formed from a metal with Eu-chalcogenide ferromagnetic semiconductors offer a potential means of overcoming this difficulty. We have made rectifying junctions of EuS:Eu on In. The results indicate: 1) a large resistivity peak at zero-bias voltage which, in the ferromagnetic region, has a strong magnetic-field dependence, and 2) a resistance maximum near 30 mV which has been tentatively assigned to excitation of collective modes in the bulk of the semiconductor. We interpret the present results by considering excitation of ferromagnetic magnons in the barrier region.

Spin-disorder Scattering and Band Structure of the Ferromagnetic Chalcogenide Spinels *by C. Haas, p. 282.* Magnetic semiconductors are characterized by the presence of charge carriers and magnetic moments. The interaction between the charge carriers and the magnetic moments leads to a spin splitting of the energy bands, and to spin-disorder scattering of the charge carriers. The result is a strong influence of magnetic properties on the transport properties. The theory of these effects is discussed in the first part of this paper. In the second part two models for the band structure of $CdCr_2Se_4$ are discussed, and compared with experimental data on the optical properties and the transport properties.

Hole and Electron Bands in *n*-type $CdCr_2Se_4$ *by L. R. Friedman and A. Amith, p. 289.* A phenomenological model is presented to explain the anomalous temperature dependencies of the electrical resistivity and the Hall and Seebeck coefficients of indium-doped $CdCr_2Se_4$ with selenium deficiencies. The model postulates the existence of a hole band below localized donor levels, well above the intrinsic valence band. The assumed relative motions of the hole band and the donor level as the temperature is lowered, together

with the optically deduced downward motion of the conduction band, are adequate to explain the data in a consistent manner. It is hypothesized that the hole band as well as the donor levels are related to the combination of indium ions and selenium deficiencies.

High-field Nonohmic Behavior of the *p*-type Ferromagnetic Semiconductor $Ag_xCd_{1-x}Cr_2Se_4$ *by B. Vural, p. 292.* The high-field longitudinal magnetoresistance of the ferromagnetic (polycrystalline) *p*-type semiconductor $Ag_xCd_{1-x}Cr_2Se_4$ has been measured as a function of temperature and applied magnetic and electric fields. It is suggested that the observed "anomalies" may be related to the possible spin wave-carrier wave interactions in these materials.

Comments on Electronic Transport in Transition Metal Oxides *by H. P. R. Frederikse, p. 295.* Several aspects of electronic transport in nonmagnetic and magnetic transition metal oxides are reviewed. These include high- and low-temperature measurements of conductivity, the Hall effect and the Seebeck effect, and their analysis in terms of the electronic energy structure. Particular emphasis is put on the temperature dependence of the Hall mobility, which gives essential information concerning the correct description of the energy states and the scattering of the charge carriers. The second half of the paper discusses the relation between the transport properties and the magnetic ordering. The properties of $LaCoO_3$ together with an interpretation suggested by Goodenough are presented to illustrate this point.

Optical Properties of the Europium Chalcogenides *by J. O. Dimmock, p. 301.* The measured optical properties of the Eu chalcogenides are surveyed in an attempt to determine those aspects of the electronic structure of these materials that have been established. Optical absorption as well as optical and magneto-optical reflectivity data are discussed, along with the results of photoconductivity, photoluminescence and photoemission measurements and of magneto-optical measurements in the vicinity of the absorption edge. It is concluded that the fundamental absorption edge is due to the onset of Eu^{++} 4f to 5d transitions of the type 4f $^7(^8S_{7/2}) \rightarrow$ 4f $^6(^7F_J)5d(T_{2g})$ and that a higher energy reflectivity peak is primarily due to 4f $^7(^8S_{7/2}) \rightarrow$ 4f $^6(^7F_J)5d(E_g)$ transitions, although anion p-valence band to Eu conduction band transitions may also be involved. The principal unanswered questions involve the relative positions of the Eu 6s and $5d(T_{2g})$ states, the breadth of the 5d levels and the role played by exciton effects in the 4f to 5d optical transitions.

Optical Reflectance Study of Magnetic Ordering Effects in EuO, EuS, EuSe and EuTe *by C. R. Pidgeon, J. Feinleib, W. J. Scouler, J. O. Dimmock, and T. B. Reed, p. 309.* The reflectivity of the ferromagnetic semiconductors EuO, EuS and EuSe has been measured as a function of temperature and light polarization in an orienting magnetic field. In the energy range from just above the absorption edges to about 5.0 eV, there are two prominent features, E_1 and E_2, which change with the magnetic order, indicating exchange splittings of the 5d states. Antiferromagnetic EuTe shows a different structure in the E_1 and E_2 peaks. However, with a large magnetic field applied (> 40 kOe) the spectrum becomes characteristic of the other ferromagnetic europium chalcogenides suggesting a phase transition to parallel spin alignment at $H \approx 80$ kOe. The effect provides direct experimental confirmation of the band theory prediction that there are superlattice splittings in the band structure of an antiferromagnetic crystal.

Magneto-optical Investigation of the Band Edge of $CdCr_2S_4$ and Related Absorption Measurements on Cr-doped $CdIn_2S_4$ *by S. Wittekoek and P. F. Bongers, p. 312.* The $^4T_1$ and $^4T_2$ crystal-field transitions of Cr^{3+} have been observed in the absorption spectrum of $CdIn_2S_4$(Cr). From the similarity between the temperature dependence of the $^4T_2$ band and the reported blue shift of the absorption edge of $CdCr_2S_4$ it is concluded that in $CdCr_2S_4$ this edge is caused by the $^4T_2$ absorption band of the Cr^{3+} ions. The polar magneto-optic Kerr effect between 560 and 700 nm and the Faraday rotation between 800 and 8000 nm are reported for $CdCr_2S_4$. The Kerr effect spectrum indicates that the intrinsic band edge of $CdCr_2S_4$ is at 1.91 eV at 60K and shifts to lower energies with decreasing temperature.

Influence of Magnetic Ordering on the Faraday Effect in $CdCr_2Se_4$ *by D. Kuse, p. 315.* Measurements of the magneto-optical rotation in $CdCr_2Se_4$ at wavelengths between 0.9 and 1.3 μm are reported. In the paramagnetic state, the rotation passes a minimum with decreasing wavelength and changes sign at the absorption edge. The Verdet constant is proportional to the paramagnetic susceptibility ($V = -18$deg/kOe-cm at 300K and $\lambda = 1.05$ μm). In the ferromagnetic state the Faraday effect is large and the sign reversal very pronounced; e.g., the rotation changes by 6.5×10^4 deg/cm in a wavelength interval of 400 Å in saturated material at 93K. The photon energy at which the sign reversal occurs shows a strong temperature-dependent red shift; the temperature dependence is similar to that of the absorption edge. At low temperatures an additional rotational minimum appears that is subject to the same red shift.

Magnetic Field Dependence of Indirect Transitions in Ferromagnetic Semiconductors *by R. M. White, p. 318.* The optical absorption coefficient for magnetic semiconductors has been calculated for indirect transitions in which the intraband scattering arises from an s-d or s-f exchange interaction instead of the usual phonon mechanism. The temperature and magnetic field dependence of the resulting absorption coefficient are discussed.

Photoinduced Magnetic Effects in YIG(Si) *by E. M. Gyorgy, J. F. Dillon, Jr., and J. P. Remeika, p. 321.* This paper summarizes the recent investigations of photoinduced effects in magnetic materials. To date it has been shown that the uniaxial anisotropy, strain, linear dichroism, coercive force

and initial permeability can be modified by infrared radiation. The theory interpreting the coercive force and permeability experiments differs from the model used to describe the first three effects and is not discussed here. The first three effects can be interpreted fairly well in terms of a model which has single Fe^{2+} ions preferentially occupying inequivalent octahedral sites. It is shown that with polarized light more than half of the available Fe^{2+} ions can be selectively moved among specific types of sites. Irradiation with unpolarized light essentially leads to a distribution appropriate for thermal equilibrium at the temperature of the sample.

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Coding for Error Control in a Computer-Manufacturer's Environment: A Foreword *by R. T. Chien, p. 342.*

Coding Schemes for Reduction of Intersymbol Interference in Data Transmission Systems *by H. Kobayashi, p. 343.* Various coding schemes and their effects on intersymbol interference in pulse amplitude modulation systems are discussed. First, the relation between imperfections in the baseband-equivalent channel and intersymbol interference is clarified and applied to explain the effect of correlative level coding and Gorog's frequency concept codes in reducing intersymbol interference. Another coding scheme is then introduced: construction of codes in the time domain with intersymbol interference directly in mind. A decimal code of length 4 and an alphanumeric code of length 6 are proposed as practical codes and their properties are discussed. Simulation results are presented to give quantitative comparison of these coding techniques. Curves of the vertical eye-opening vs transmission rate have been produced and we show that codes designed in the time domain achieve better performance than both the frequency concept codes and the conventional codes for a wide class of channel characteristics.

Introduction to Pseudoternary Transmission Codes *by A. Croisier, p. 354.* This paper describes many of the pseudoternary (PT) codes (twinned, bipolar, partial response, etc.) used in data transmission. In these, binary information is transmitted through three-level rather than binary pulse codes for controlling the power distribution in the frequency spectrum, improving clock recovery, allowing error detection or for just increasing the binary data rate. Linear and nonlinear PT codes are considered, the latter being divided into alphabetic and nonalphabetic codes. Among the nonalphabetic codes, emphasis is given to the modified bipolar codes used in pulse code modulation systems. Two recently developed codes of this type are described: High Density Bipolar (HDB) and Compatible High Density Bipolar (CHDB). They are particularly suitable for PCM transmission on repeatered lines.

Another nonalphabetic code, the Transparent Interleaved Bipolar (TIB) is presented for the first time. This code features all the advantages of partial-response (or Interleaved Bipolar) signalling and, in addition, guarantees a minimum density of pulses, regardless of the data.

Application of Partial-response Channel Coding to Magnetic Recording Systems *by H. Kobayashi and D. T. Tang, p. 368.* A magnetic recording channel can be regarded as a "partial-response" channel because of its inherent differentiation in the readback process. The conventional NRZI method of recording is shown to be equivalent to the "precoding" of this particular partial-response channel, the purpose of which is to limit the propagation of error in the channel output. Using this new viewpoint, one can readily adopt an error detection scheme (developed for general partial-response channels) that takes full advantage of the inherent redundancy in the three-level channel output. The detection scheme is optimum in the sense that it detects all detectable errors with minimum delay.

The paper also describes a new high-density recording method, named the "Interleaved NRZI," which is obtained by molding an ordinary recording channel into a different type of partial-response channel, resulting in a potential increase in information density. Implementation of the corresponding optimum error detection scheme is also presented.

Finally, performance of these error detection schemes is evaluated in terms of probabilities of detecting single and double errors within a certain finite delay.

Sequence-state Methods for Run-length-limited Coding *by P. A. Franaszek, p. 376.* Methods are presented for the encoding of information into binary sequences in which the number of ZEROS occurring between each pair of successive ONES has both an upper and a lower bound. The techniques, based on the state structure of the constraints, permit the construction of short, efficient codes with favorable error-propagation-limiting properties.

Error Correction for IBM 800-bit-per-inch Magnetic Tape *by D. T. Brown and F. F. Sellers, Jr., p. 384.* The 800-bit-per-inch magnetic tape units that are components of IBM System/360 can correct error bursts of unlimited length in any one of their nine tape tracks. The correction technique employs a modified cyclic code in conjunction with a parity bit in each nine-bit character. There are nine check bits in the modified cyclic code and these form a check character at the end of every record. To perform the correction, a record in which an error has been detected must be reread. Errors involving more than one track within the same record are detected but are not correctable. This error correction technique operates during both read-forward and read-backward operations, and on records of any length.

Orthogonal Latin Square Codes *by M. Y. Hsiao, D. C. Bossen, and R. T. Chien, p. 390.* A new class of multiple-error correcting codes has been developed. Since it belongs to the

class of one-step-decodable majority codes, it can be decoded at an exceptionally high speed. This class of codes is derived from a set of mutually orthogonal Latin squares. This mutually orthogonal property provides a class of codes having a unique feature of "modularity." The parity check matrix possesses a uniform pattern and results in a small number of inputs to modulo 2 adders. This class of codes has m^2 data bits, where m is an integer, and $2tm$ check bits for t-error correcting.

A Class of Optimal Minimum Odd-weight-column SEC-DED Codes *by M. Y. Hsiao, p. 395.* The class of codes described in this paper is used for single-error correction and double-error detection (SEC-DED). It is equivalent to the Hamming SEC-DED code in the sense that for a specified number k of data bits, the same number of check bits r is used. The minimum odd-weight-column code is suitable for applications to computer memories or parallel systems. A computation indicates that this code is better in performance, cost and reliability than are conventional Hamming SEC-DED codes.

***b*-Adjacent Error Correction** *by D. C. Bossen, p. 402.* A high-speed method is derived for single-symbol error correcting Reed-Solomon and Hamming type codes. A matrix description is used for implementation of the codes, in which single-error correction in the Galois field 2^b corresponds to correcting a block of b bits in a binary field. The resulting codes correct not only single-bit errors but also single clusters of b-adjacent-bit errors.

Error Control for Terminals with Human Operators *by D. T. Tang and V. Y. Lum, p. 409.* The man-machine interface at any terminal in a computer system is a likely source of error and can be regarded as a noisy channel. Certain data, such as ID numbers, can be precoded to protect against most-likely errors, including transposition of adjacent symbols and substitutions, as well as deletions and insertions. This paper first considers certain basic requirements for error detection with minimum redundancy. An efficient special coding scheme designed for decimal terminals is described next. Finally, certain cyclic codes are shown to be adaptable to transposition error control when appropriate decoding schemes are implemented.

Three Measures of Decoder Complexity *by J. E. Savage, p. 417.* Three measures of the complexity of error correcting decoders are considered, namely, logic complexity, computation time and computational work (the number of logical operations). Bounds on the complexity required with each measure to decode with probability of error P_e at code rate R are given and the complexity of a number of ad hoc decoding procedures is examined.

An Analysis of the Effectiveness of Hybrid Transmission Schemes *by E. Y. Rocher and R. L. Pickholtz, p. 426.* A comparison is made of the performance of pure retransmission, forward error correction and hybrid (error detecting/correcting) schemes for data transmission in a noisy (probability of error, $P > 10^{-4}$) binary symmetric channel. The performance calculations are based on the use of BCH codes for error detection and correction up to the full correction capability of the code. It is shown that a probability of undetected error of less than 10^{-9} error/bit, can be achieved by correcting only a few errors while retaining a reasonable throughput and a very low retransmission rate. The best codes in the class considered are specified and the complexity of instrumentation is estimated. Finally, various combinations of possible systems employing half duplex and reverse channel operation are used in a comparison of the transmission schemes. For line error rate worse than 10^{-4} error/bit, a hybrid system operating with a reverse channel is superior to the other possibilities.

Maximal Group Codes with Specified Minimum Distance *by A. M. Patel, p. 434.* All n-digit maximal block codes with a specified minimum distance d such that $2d \geq n$ can be constructed from the Hadamard matrices. These codes meet the Plotkin bound. In this paper we construct all maximal group codes in the region $2d \geq n$, where d is a specified minimum distance and n is the number of digits per code word. Unlike the case of block codes, the Plotkin upper limit, in general, fails to determine the number of code words $B(n, d)$ in a maximal group code in the region $2d \geq n$. We show that the value of $B(n, d)$ largely depends on the binary structure of the number d. An algorithm is developed that determines $B(n, d)$, the maximum number of code words for given d and $n \leq 2d$. The maximal code is, then, given by its modular representation, explicitly in terms of certain binary coefficients and constants related to n and d. As a side result, we obtain a new upper bound on the number of code words in the region $2d < n$ which is, in general, stronger than Plotkin's extended bound.

Low Energy Electron Diffraction (LEED) Spectra: Aluminum *by F. P. Jona, p. 444.* The intensities of low energy electron beams specularly and nonspecularly diffracted from {100}, {110} and {111} surfaces of aluminum have been measured in a display-type LEED system as functions of electron energy, angle of incidence and azimuthal angle. Several of the measured and normalized spectra are presented, and the procedures followed in aligning the sample, reducing stray magnetic fields, and collecting and normalizing the data are described.

Silicon Defect Structure Induced by Arsenic Diffusion and Subsequent Steam Oxidation *by S. Dash and M. L. Joshi, p. 453.* Misfit dislocation nets are known to occur when very high amounts of phosphorus and boron are diffused into silicon single-crystal wafers. Diffusion of arsenic in silicon is not known to produce such dislocations. Through transmission electron microscopy it is shown in this paper that diffusion of high amounts (up to 1.6×10^{21} atoms/cm^3) of arsenic creates Frank hexagonal loops on (111) planes parallel

to the diffusion surface, and stacking faults on the inclined {111} planes, instead of misfit dislocation nets (the latter are still not observed). These faults and loops are found to be extrinsic, and are thought to be due to insertion of extra silicon layers in the matrix where the stacking fault energy is decreased by arsenic atoms. The driving force for the generation of loops and faults is shown to be the concentration gradient rather than fast cooling.

Reduction of Electromigration in Aluminum Films by Copper Doping *by I. Ames, F. M. d'Heurle, and R. E. Horstmann, p. 461.* We have found that the lifetime of aluminum films subjected to high current densities at elevated temperatures can be increased by the addition of copper. Previous studies have indicated that the failure mechanism is a combination of electromigration-induced phenomena, including nucleation and growth of voids, which are gated primarily by material transport along grain boundaries. On the basis of the present study, it appears that the presence of copper causes an appreciable retardation in the rate at which this overall combination of processes takes place, thereby producing a considerable increase in lifetime.

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The Conference on Holography and the Computer *by J. A. Jordan, Jr., p. 476.*

Some Effects of Fourier-domain Phase Quantization *by J. W. Goodman and A. M. Silvestri, p. 478.* If the Fourier transform of a function $g(x)$ is quantized, the function recovered by inverse transformation differs from $g(x)$. By means of a biased limiter model, the effects of Fourier-domain phase quantization are studied. Amplitude information is assumed fully retained, while phase is quantized to N equally spaced levels. The recovered function is shown to consist of several different contributions, the relative strengths of which depend on the number of phase quantization levels. Several specific examples are given. Motivation and interpretation are presented in terms of digitally constructed holograms.

Incoherent Filtering Using Kinoforms *by J. C. Patau, L. B. Lesem, P. M. Hirsch, and J. A. Jordan, Jr., p. 485.* Incoherent optical filtering with the kinoform used as a filtering element is discussed. Kinoform theory is briefly reviewed and initial results with "fan" and correlation filters are presented.

Acoustic Holography with Crossed Linear Arrays *by D. M. Milder and W. H. Wells, p. 492.* This paper is an analysis of how acoustic (or microwave) holography can be applied to large masses, such as natural bodies of water or the earth, by means of a linear array of microphones and by scanning with one or more transmitters to produce holographic phase shifts. This type of hologram, in which the phased array has a conical antenna pattern, is shown to be superior to the area hologram for computing images in the near field. Computer simulations are given of virtual holograms and image reconstructions for specular and diffuse reflectors; simulations are also made for the case of pulse holography, which yields genuine three-dimensional images with reduced highlight distortions.

Structural-information Storage in Holograms *by J. T. Winthrop, p. 501.* The number of degrees of freedom, or structural-information content, of the object wave field recorded in a Leith-Upatnieks hologram is expressed in terms of the resolving power and dimensions of the recording medium, the coherence properties of the primary illumination and the position of the point reference source. In contrast with previous studies, the calculation does not involve the paraxial approximation. It is shown that of all holograms, the Fourier-transform hologram makes the most efficient use of available resolving power and coherence length.

Laser Speckle and Its Elimination *by D. Gabor, p. 509.* "Objective" speckle arises from the uneven illumination of an object with a multiplicity of waves that interfere at its surface. "Subjective" speckle arises at rough objects even if they are illuminated evenly by a single wave. The noise in the image is caused by the interference of the point-figures, which have random phases. Subjective speckle cannot be reduced except by extending the aperture. On the other hand the "objective" speckle in a plane, for instance in the plane of a transparency, can be reduced, and in the limit made invisible, by a special type of wide-angle illumination. This consists of a one-parameter family of plane waves, which can be produced by diffraction at a special grating, or two crossed gratings, close to the object plane. This makes it possible to produce multiple holograms, with the same insensitivity to dust or scratches as diffused holograms, but without any visible speckle in the reconstruction.

A Theory of Granularity and Bleaching for Holographic Information Recording *by H. W. Lorber, p. 515.* The Kelly three-stage model of photographic information recording is a mathematical model of black-and-white silver-halide film with granularity neglected. In the work reported here, the theory is extended for use in phase-holographic applications. Granularity effects are contained in the fourth and final stage, a two-dimensional, nonhomogeneous, filtered Poisson process. The output of this stage is a sample function of the random process that describes the pattern of modification of the emulsion. Formulas for the signal-to-noise ratio of a hologram and the optimum granular behavior are derived as examples of the use of the granularity model.

Noise and Distortion in Photographic Data Storage *by D. G. Falconer, p. 521.* Noise and distortion limit the usefulness of the photographic transparency as a data-storage medium. The noise, which tends to be multiplicative, derives from the random distribution of silver grains in the photographic image, as well as from thickness variations in the developed emulsion. Distortion, on the other hand, results from 1) the nonlinear relation between transmittance and exposure, 2) the finite width of the emulsion's point-spread function and 3) the

existence of an adjacency-enhancement function. Although grain noise remains intrinsic and untreatable, nonlinear distortion—both global and local—may be treated by lowering the contrast of the exposure pattern or, preferably, by recording the data in the form of a phase-modulated carrier wave, as in holography. A solution to the remaining difficulty, namely, linear-global distortion, is obtained through the use of high-resolution, Lippmann-type emulsions.

Characteristics of Dielectric Holograms *by J. Upatnieks and C. D. Leonard, p. 527.* The diffraction efficiency and signal-to-noise ratio for two-dimensional and volume diffuse-signal-beam holograms are calculated and experimentally determined. Calculations are based on the statistical properties of the signal beam, and exact integrals rather than series approximations are used. High signal-to-noise ratio and high diffraction efficiency are possible, with the peak calculated diffraction efficiency being 22% for two-dimensional and 64% for volume holograms. The experimentally achieved efficiencies were 12% for two-dimensional and 36% for volume holograms.

High-efficiency Phase-hologram Gratings *by A. Schmackpfeffer, W. Järisch, and W. W. Kulcke, p. 533.* Optimum conditions for the generation of high-efficiency hologram gratings are presented. The most efficient phase holograms were obtained for exposures 10 to 20 times larger than those for optimally exposed amplitude holograms. Hologram gratings produced on Agfa Gevaert 8 E 70 recording plates diffracted 40 percent of the incident radiation into the holographic image. This experimentally obtained efficiency is 60 percent of the theoretical maximum for a hologram with a geometric parameter Q of 4.6.

A Statistical Mechanical Approach to Systems Analysis *by A. E. Ferdinand, p. 539.* The maximum entropy principle is used as the criterion for calculating the equilibrium state probabilities of a queuing or network system in which service rates are exponentially distributed. A configuration-independent partition function is given as the solution to this network problem; from this function the important properties of the system may be derived. Simple and well known examples are used to illustrate the method. A phenomenon similar to the phase transition of statistical mechanics is observed in a queuing model.

Moment Normalization of Handprinted Characters *by R. G. Casey, p. 548.* Handprinted characters can be made more uniform in appearance than the as-written version if an appropriate linear transformation is performed on each input pattern. The transformation can be implemented electronically by programming a flying-spot raster-scanner to scan at specified angles rather than only along specified axes. Alternatively, curve-follower normalization can be achieved by transforming the coordinate waveforms in a linear combining network. Second-order moments of the pattern are convenient properties to use in specifying the transformation. By mapping the original pattern into one having a scalar moment matrix all linear pattern variations can be removed. Comparison experiments with three sets of handprinted numerals showed that error rates were reduced by integral factors if the patterns were normalized before scanning for recognition.

Performance Equivalence of Suboptimally Controlled Nonlinear Systems *by R. C. Durbeck, p. 558.* A procedure is described that shows how a technique used to develop performance bounds for a large class of nonlinear dynamic systems with state-dependent control policies can be extended to determine whether a nonlinear system can be controlled so that it is at least "performance equivalent" to an associated optimally controlled linear system. A procedure for generating one or more control policies to attain this equivalence is also discussed. An example illustrates the fact that more than one control policy may satisfy the equivalence criterion.

Concurrent Error Detection for Group Look-ahead Binary Adders *by G. G. Langdon, Jr. and C. K. Tang, p. 563.* This paper presents an evaluation of the relative merits of two schemes for performing concurrent error detection in group look-ahead adders. One of the schemes is a residue mod 3 check and the other is a parity prediction check. The Boolean statements that define the operation of group look-ahead adders, concurrent error detection and the Boolean difference serve as background for interpreting the results of the study. The Boolean difference is a tool for calculating the "coverage" of elements in a logical network by error-checking schemes. Some weaknesses in prior studies of coverage calculation are brought to light. Tables showing the number of circuit elements in the various portions of adder and error-checking circuits are given. It is shown that the residue mod 3 check adder is not economical unless the addition operands are already provided with the mod 3 check bits. Thus, a worthwhile comparison of the checking schemes should not proceed without considering the overall data flow checking strategy. In machine organizations with three or more data transfer checks, the parity-checked adder seems to offer a cost advantage.

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Plant automation in IBM: a Preface *by R. M. Neudecker, p. 588.*

Integrated Manufacturing Systems: Architectural Considerations *by C. Kinberg and B. W. Landeck, p. 589.* This paper is divided into two main parts. The first is concerned with definitions of concepts and terms of importance to the architect of integrated manufacturing systems. It describes the operational environment, how the manufacturing systems are going to be used, and a variety of system requirements. Priorities are established and a set of guiding principles for system design are proposed. In the

second part, three basic system structures are analyzed and evaluated in terms of the previously stated priorities and guiding principles. The relation of integrated manufacturing systems to other complex systems is shown to illustrate how generally applicable many of the findings derived from knowledge of the manufacturing environment are to the design of systems for other application fields.

The paper concludes by restating the key requirements and formulates what appears to be the greatest challenge for the system architect. That is, the creation of an architectural framework within which the system designers can structure manufacturing systems capable of handling besides the planned tasks a variety of unforeseen applications. Readers familiar with the plant environment and the terms and concepts associated with it may skip the first sections and start with System Requirements. We would, however, advise even the experienced reader to review the definition of real-time systems, which we believe is new.

An Integrated Manufacturing Process Control System: Implementation in IBM Manufacturing *by J. E. Stuehler, p. 605.* An integrated manufacturing process control system has been developed and implemented in several of IBM's manufacturing facilities to control process and test equipment used in the manufacture of IBM products. The system architecture consists of a central, on-line, IBM 360 Data Processing System operating under OS/360 which communicates via high-speed data channels to satellite IBM 1800, 1130 and System/360 processors.

These satellite processors control various types of process and test equipment. The central system serves as a common data bank and an input/output device for the satellite processors. In addition, the central system performs data analysis and management reporting on information obtained from the manufacturing floor. This paper discusses the general system requirements and specifications along with the hardware and software required to implement those requirements and specifications. Also discussed are problems which were encountered after initial development and plans for future development.

A Transmission Control Unit for High-speed Computer-to-computer Communication *by F. W. Thoburn, p. 614.* An integral part of a process control and testing system used in several IBM plants is the transmission control unit (TCU). This paper discusses the design of the TCU, which provides the communication link between as many as 512 satellite computers and a central computer. It uses a microprogrammed polling scheme to establish connection with the satellites that need service and it permits messages of unrestricted length to be transmitted in either direction at the rate of 2.5×10^6 bits/sec over coaxial cables. With the aid of noise suppression circuits, it operates in the electrically noisy factory environment at an error rate of less than 10^{-8}.

PCOS: A Process Control Extension to Operating System/360 *by J. R. Calva, p. 620.* This paper discusses the design and implementation of an extension to IBM Operating System/360 that is called PCOS and is intended specifically for use in "real-time" control of IBM manufacturing processes and testing. The most important part of PCOS is a Real-Time Control Program (RTCP) which is initiated at system start-up time as a "never-ending" task. The RTCP controls the execution of application programs and permits system response to requests for their execution within a time on the order of 100 msec. Other contributions are an "express path" for handling input/output operations, an "interpartition communication" program that provides common core storage for use during the execution of application programs, and an appendage to the OS/360 supervisor program to serve a specially designed high-speed multiplexor called the "transmission control unit."

Computer-aided Testing and Fabrication of Magnetic Tape Heads *by R. B. Fischer, C. M. Cox, and C. Holdinsky, p. 633.* A data collection and analysis system has been developed to control magnetic tape head testing and provide data analysis for manufacturing process control. Data collection is achieved by a system of test terminals controlled by an IBM 1130 computer, which is a satellite of an IBM System/360 Model 50 computer. The data base made possible by this system provides a means of tracing recurring failures and leads to a better understanding of the effects of process variables on the completed product.

Precision Automatic Measuring of *X-Y* Coordinates *by M. R. Radio, S. A. Schmitt, S. H. Lewis, T. G. Merry, and J. L. Evjen, p. 641.* This paper reports the development of a computer-controlled machine for non-contact inspection of manufactured parts. The machine, called PAMM (Precision Automatic Measuring Machine), is capable of providing "on-the-fly" measurements accurate to within 100 microinches. The intersection of a rotating spiral slot with a stationary linear slot produces a moving aperture for scanning in small increments over a projected, enlarged image of a part. The scanner assembly moves along an overhead cantilever beam in the x direction, and the part being inspected moves in the y direction along the machine base; position in each direction is monitored by a separate laser interferometer.

In the paper conventional methods of coordinate measuring are briefly reviewed, the details of the new design are presented, some experimentally obtained measurements are given, measurement errors induced by photodetector shot noise and aperture roughness are analyzed, and the computer-control and data-analysis techniques are discussed.

IBM System/7 and Plant Automation *by T. J. Harrison, R. L. Homiak, and G. U. Merckel, p. 652.* The recently announced IBM System/7 was developed for use in a broad range of data acquisition and control applications and provides the foundation for comprehensive plant automation

applications. Its unique modular structure and broad spectrum of features satisfy the basic plant automation requirements described in the paper by Kinberg and Landeck in this issue. In the present paper the functional characteristics, important design features, and the basic architectural concepts of hardware and software are discussed. An example of the use of this new system in the automation of the System/7 manufacturing process itself is provided to illustrate its use in the testing of complex electronic assemblies as part of an integrated plant automation system.

IBM 2790 Digital Transmission Loop *by R. O. Hippert, Jr., p. 662.* A tandem connection of terminals for a data collection system has certain desirable advantages over the more common radial configuration. To make use of these advantages, high-speed transmission links are required. This paper describes the transmission capability necessary for a high-speed digital data repeater when it is restricted to an in-house environment. The transmission techniques discussed are implemented in the IBM 2790 Data Communication System.

The Percus-Yevick Theory and the Equation of State of the 6:12 Fluid *by D. J. Henderson, J. A. Barker, and R. O. Watts, p. 668.* The Percus-Yevick theory can be used to calculate the pair distribution function and from this the equation of state. The conventional method is to calculate the pressure of compressibility directly, unfortunately yielding poor results for the 6:12 fluid at low temperatures. In this paper results are obtained using an indirect method, in which the energy is calculated from the pair distribution function, and the equation of state is obtained by thermodynamic identities. These results are virtually in exact agreement with the machine calculation results for the 6:12 potential and with experimental results for argon.

Iterated Consensus Method for Multiple-output Functions *by M. P. Marcus and W. H. Niehoff, p. 677.* The iterated consensus method for obtaining prime implicants of Boolean functions has several advantages with respect to the conventional tabular method. However, when one attempts to apply the iterated consensus method to multiple-output functions using the rules set forth in the existing literature, it is possible that some of the prime implicants will not be produced. This communication presents an algorithm which assures that all prime implicants of multiple-output functions will be found.

On the Correlation Matrices of Trigonometric Product Functions *by R. F. Filipowsky, p. 680.* Sets of waveforms called TPF's, which are products of trigonometric functions, may have application in communications technology, network analysis and signal processing. This communication briefly reviews the characteristics of TPF's and presents methods for calculating their cross-correlation coefficients when 1) all TPF's in a set have harmonic factors with the same set of values, and 2) the harmonic factors have different values.

Man-made Superlattice Crystals *by A. E. Blakeslee and C. F. Aliotta, p. 686.* Multiple closely spaced layers of $GaAs_{1-x}P_x$, which approximate a one-dimensional crystalline superlattice, have been created by periodically pulsing PH_3 into an AsH_3-PH_3-Ga-HCl vapor-growth apparatus. The phosphorus mole fraction varies between maximum and minimum values with a period typically less than 200 Å. Structures with up to 150 such layers have been produced. The crystal growth process and methods of characterization are discussed briefly.

Comment on "A Topological Theory of Domain Velocity in Semiconductors" *by E. J. Aas, p. 689.* Recently Gunn presented a simple formula for the domain velocity in a "diffusion-controlled" semiconductor, based on topological arguments. It is shown that these arguments are generally not valid. The apparent agreement between Gunn's formula and Hauge's computer simulation is briefly discussed.

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Digital Simulation of the Global Transport of Carbon Monoxide *by H.-C. W. Kwok, W. E. Langlois, and R. A. Ellefsen, p. 3.* A numerical model of the general atmospheric circulation is used to simulate the global transport of carbon monoxide. The sources are estimated from gasoline consumption data. Since the strongest sources lie in the northern hemisphere belt of strong prevailing westerly winds, "chaining" effects are quite pronounced. Emissions generated in one populous area are soon superimposed upon those of the next area downwind. Subscale cumulus convection, which is parameterized in the model, accounts for a significant fraction of the vertical CO transport.

A New Technique for Gas-phase Kinetic Spectroscopy of Molecules in the Triplet State *by H. E. Hunziker, p. 10.* A recently developed experimental method is described to populate by Hg photosensitization and observe by absorption spectroscopy the triplet states of polyatomic molecules in the gas phase; detailed discussion and analysis of the experiment are given. The technique can be used to investigate triplet states that cannot be populated efficiently by the intersystem crossing process and to detect triplet absorption bands located within the wavelength range of ground-state absorption of a molecule. A modulation scheme, based on a novel type of Hg resonance light source—an rf-driven toroid capable of modulation frequencies up to 250 kHz—is used for monitoring the optical absorption (by phase-sensitive detection) and measuring the lifetime of the transient species. Sensitivity is comparable with that of flash spectroscopy for transients that decay by a second-order process. Results obtained for several aromatic hydrocarbons are reviewed. New transitions were detected by this method for triplet-state naphthalene, and the absorption spectra and decay kinetics of triplet-state benzene and toluene were measured for the first time. Some applications of the technique to problems other than triplet-state spectroscopy are illustrated or outlined.

Photoconduction in Aromatic Hydrocarbons *by G. Castro, p. 27.* Photoconduction has been observed in single crystals of benzene, naphthalene, biphenyl and pyrene using the pulse technique. Experimental procedures have been found for the purification and crystal growth of the materials that produce specimens whose charge carrier lifetimes are sufficiently long to allow the measurement of drift mobilities, and thus to determine the number of charge carriers produced per pulse. A single-photon generation mechanism was observed only in pyrene. The other materials exhibited a photogeneration mechanism that depended quadratically on light intensity and was determined to be exciton-exciton collision ionization.

Photochemical Addition of Benzene to Cyclobutene *by R. Srinivasan, p. 34.* The major products of the photochemical addition at 253.7 nm of benzene to cyclobutene in solution were found to be tetracyclo[5.3.0.$0^{2,10}$$0^{3,6}$]-decene-8 and tricyclo[4.2.2.$0^{2,5}$]deca-7,9-diene, which arise from 1,3- and 1,4-additions. The quantum yields for both reactions were independent of benzene concentration below 2*M* but decreased at higher concentrations. The maximum quantum yields that were obtained are 0.81 and 0.09 for the 1,3- and 1,4-reactions, respectively, indicating that the former reaction is a very efficient process.

The 1,3-addition may occur from the singlet ($^1B_{2u}$) state of benzene, as has been suggested in the literature. The origin of the 1,4-addition is not clear, but it seems unlikely that it occurs from the triplet state of benzene.

Preparation and Thermodynamics of Some Homologous Nitrones, a New Group of Liquid Crystals *by W. R. Young, I. Haller, and A. Aviram, p. 41.* To investigate the mesomorphic behavior of aldonitrones, a series of 13 homologs of N-(*p*-alkoxyphenyl)-α-anisylnitrones was prepared and characterized. Although most of these substances exhibit normal nematic or smectic mesophases, the trend in nematic-isotropic transition temperatures to increase as a function of alkoxy chain length is an exceptional occurrence. Comparison of our data with that of analogous compounds previously reported indicates that thermal persistence of the nematic phase of these compounds increases in the following order: 4,4'-dialkoxybenzylideneaniline, 4,4'-dialkoxyazobenzene, N,α-di-(4-alkoxyphenyl)-nitrone, 4,4'-dialkoxyazoxybenzene. In addition, the phase transitions were investigated by means of differential scanning calorimetry. The entropies of the mesophase-isotropic transitions of the nitrones imply that the long alkoxy chains, in contrast to a widely held belief, are not restricted to a single conformation in the mesophase.

Polymorphism in Cholesteryl Esters: Cholesteryl Palmitate *by M. J. Vogel, E. M. Barrall II, and C. P. Mignosa, p. 52.* The thermal transitions in cholesteryl palmitate, an ester having liquid-crystalline states, have been evaluated and compared to previously reported data. A sample synthesized from carefully purified cholesterol and palmitic acid using *p*-toluene sulfonic acid compared directly with previously reported data. A sample of recrystallized ester from a commercial source showed a slightly depressed solid-to-mesophase transition temperature. However, the mesophase proved to be smectic, commonly reported as monotropic with respect to the solid phase. Both smectic-to-cholesteric and cholesteric-to-isotropic-liquid transitions were sharp, indicating a pure material. It is postulated that a specific impurity, possibly an isomeric cholesterol ester, is responsible for this previously unreported effect. This effect of related compound interaction has been reported for nematic-mesophase-forming compounds. Thin layer chromatography, microscopy, depolarized light intensity analysis, differential scanning calorimetry and NMR spectroscopy data are offered in support of this postulate.

On Measuring Nuclear Magnetic Shielding Anisotropies in Liquid Crystal Solvents *by C. S. Yannoni, p. 59.* Up to the

present time nuclear magnetic shielding anisotropies ($\Delta\sigma$) have been determined in nematic liquid crystal solutions by comparing the chemical shifts in the isotropic and nematic phases. Unknown changes in solvent-induced shifts arising from the isotropic → nematic phase transition constitute a serious problem in the interpretation of the results. To avoid the ambiguities inherent in these shifts, a method is described for measuring $\Delta\sigma$ in the nematic phase alone. This technique has been used to determine $\Delta\sigma$ in a variety of ^{1}H- and ^{19}F-containing molecules and the results are compared with those obtained by the two-phase method.

Application of Probabilistic Decoding to Digital Magnetic Recording Systems *by H. Kobayashi, p. 64.* A digital magnetic recording system is viewed in this paper as a linear system that inherently includes a correlative level encoder. This encoder can be regarded as a linear finite-state machine like a convolutional encoder. The maximum likelihood decoding method recently devised by Viterbi to decode convolutional codes is then applied to digital magnetic recording systems. The decoding algorithm and its implementation are discussed in detail.

Expressions for the decoding error probability are obtained and confirmed by computer simulations. It is shown that a significant improvement in the performance with respect to other methods is achievable by the maximum likelihood decoding method. For example, under the Gaussian noise assumption the proposed technique can reduce raw error rates in the 10^{-3} to 10^{-4} range by a factor of 50 to 300. These results indicate that the maximum likelihood decoding method gains as much as 2.5 dB in signal-to-noise ratio over the conventional bit-by-bit detection method.

A New High-sensitivity Organic Photoconductor for Electrophotography *by R. M. Schaffert, p. 75.* A new organic photoconductor has been developed, consisting essentially of a 1:1 molar ratio of one molecule of 2, 4, 7-trinitro-9-fluorenone (TNF) to one monomer unit of poly-N-vinylcarbazole (PVCz). This photoconductor (1:1 TPC) is nearly panchromatic in the visible range of the spectrum and has a white-light sensitivity approximately equal to that of amorphous selenium when used for electrostatic imaging. The photosensitivity, which is due mainly to the TNF-PVCz complex, is greater for negative corona charging than for positive charging. Charge acceptance of the 1:1 TPC is high, ≈ 1200 volts for a 13μm film, indicating good dielectric strength. Dark decay of the charge is affected by substrate materials and substrate surface conditions. In general dark decay is slower for negative charging than for positive charging. Quantum efficiency (Q.E.) is nominally about 0.15 in the range of 400 to 500 nm but decreases somewhat for shorter and longer wavelengths. The Q.E. increases rather markedly with field strength, but decreases somewhat at high light intensities. Field-controlled photogeneration of carriers is indicated, and thermal measurements show a field-dependent activation energy in the range of 0.06 to 0.20 eV. The absence of residual potentials in light decay curves and the lack of a thickness effect in photodischarge currents indicate that no deep traps are present in the 1:1 TPC layers.

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Preface to papers on Mechanics of Materials *by J. L. Hibbard, p. 102.*

Wear of Electrical Contacts due to Small-amplitude Motion *by R. G. Bayer and J. L. Sirico, p. 103.* The "IBM wear model," which has previously been used to describe the wear of electrical contacts as a result of gross sliding motion, is used to describe contact wear in the case of small-amplitude sliding motion. This model was applied to a particular contact configuration on which a series of wear tests was performed. The empirical results of the tests are compared to the theoretical expressions and good agreement is found, thus indicating that the wear mechanism is essentially the same for both large- and small-amplitude sliding contact.

Effect of Hammer Length and Nonlinear Paper-ribbon Characteristics on Impact Printing *by A. L. Jones and A. J. Lavin, p. 108.* An analysis of the impact process in a particular type of high-speed printer was undertaken to determine the effect of hammer length on the contact time. The hammer is modeled as a one dimensional wave propagation medium and the paper-ribbon combination as a dissipative, nonlinear medium with hysteresis. The integrated macroscopic viscoelastic parameters for a particular impact geometry and hammer momentum were determined from a combination of the analytical model and the experiments run on an instrumented printer robot. Permanent deformation of the paper-ribbon caused by character penetration was also determined in this manner. The simulated model was then used to predict the change in dynamic behavior of such a system due to variations of the hammer length. The hammer length is shown to have only a tertiary effect on contact time in such a dissipative deformable nonlinear system. This result demonstrates that the widely discussed use of hammer length as a design parameter to control contact time in impact printing is invalid for such a dissipative system.

Adhesion and Partial Slip between Normally Loaded Round Surfaces *by P. A. Engel and H. D. Conway, p. 116.* A simple mechanism is sought to account for the frictional energy losses encountered in the mutual contact surface of two bodies pressed normally against each other. The mathematical model of Coulomb friction is assumed valid, and it is shown that slip between the contacting surfaces develops in the outlying regions of contact. This model, used in conjunction with a numerical scheme, leads to a set of nonlinear simultaneous algebraic equations in the surface tractions. Two specific cases are computed: those of a rigid sphere and of a rigid roller each pressed against an elastic medium. The relative size of the slip region is shown to depend on the

material properties. Energy dissipation during a half contact cycle is calculated, and the influence of the secondary adhesive tractions on the contact stresses is discussed.

Analysis of Defect Distribution in Transistor Structures with Reflection and Transmission X-Ray Topography *by J. K. Howard and P. J. Smith, p. 123.* Reflection and transmission x-ray topography can be combined to isolate and identify dislocations that penetrate the active junctions of transistor structures in integrated circuit wafers. This is accomplished by reconstructing the defect distribution normal to the surface as viewed in transmission (volume-sensitive) and reflection (surface-sensitive) x-ray topography. The combination of surface and bulk observations is exploited to demonstrate the effect of dislocation density on pipes (low-resistance paths from emitter to collector). A method is also described for estimating the depth of defect visibility in reflection x-ray topography.

Effect of Extremely Thin Nitrogenous Surface Films on Phosphorus-impurity Profiles in Silicon *by J. Makris, A. Ferris-Prabhu, and M. L. Joshi, p. 132.* In open-tube diffusion furnaces, nitrogen is often used as a carrier gas for impurities. Nitrogen flowing over silicon wafers at the diffusion temperature creates extremely thin surface films, which act as strong diffusion barriers. Similar barriers are formed on silicon wafers even in capsule-diffusion systems because of the residual atmosphere. Phosphorus-impurity profiles are found to be kinked due to these diffusion barriers. The position and dependence of the kinks on various diffusion parameters such as time, temperature and impurity concentration in the carrier gas are discussed. The kinks are eliminated if the formation of the thin-film barriers is avoided through use of argon or other noble gases. A mathematical model is presented to explain the kinked behavior of the profiles.

Molecular Engineering in the Development of Materials for Thermoplastic Recording *by H. R. Anderson, Jr., E. A. Bartkus, and J. A. Reynolds, p. 140.* A number of internally plasticized copolymers and terpolymers have been prepared which are shown to be suitable for thermoplastic recording. These materials were responsive to both in-air and in-vacuum recording techniques, where the electrostatic charge is applied by corona charging or electron beams, respectively. Several of these materials were tailored for Schlieren optical readout while others possessed properties suggesting their use in recording systems requiring electron beam readout.

On the Correlation between Domain Size and Coercive Force in Grain-oriented 3.25% Si–Fe *by J. A. Pesch, p. 151.* A method is described for measuring the size of the largest spike-shaped magnetic domains on surfaces of grain-oriented 3.25% Si–Fe. Values of coercive force, obtained by using measured spike-domain size in a previously derived empirical expression correlating spike size with the coercive force in silicon-iron, are in close agreement with coercive force values obtained from $B - H$ loop measurements. This technique makes it possible to measure the coercive force on non-toroidal magnetic components used in data processing machines.

Segmentation Methods for Recognition of Machine-printed Characters *by R. L. Hoffman and J. W. McCullough, p. 153.* This paper reports an investigation of some methods for isolating, or segmenting, characters during the reading of machine-printed text by optical character recognition systems. Two new segmentation algorithms using feature extraction techniques are presented; both are intended for use in the recognition of machine-printed lines of 10-, 11- and 12-pitch serif-type multifont characters. One of the methods, called quasi-topological segmentation, bases the decision to "section" a character on a combination of feature-extraction and character-width measurements. The other method, topological segmentation, involves feature extraction alone.

The algorithms have been tested with an evaluation method that is independent of any particular recognition system. Test results are based on application of the algorithm to upper-case alphanumeric characters gathered from print sources that represent the existing world of machine printing. The topological approach demonstrated better performance on the test data than did the quasi-topological approach.

System Validation by Three-level Modeling Synthesis *by K. A. Duke, H. D. Schnurmann, and T. I. Wilson, p. 166.* The experimental three-level system modeling technique discussed in this paper can be used during the design stage of a system for identifying mismatches among the architectural, microprogramming, and hardware logic levels. Compatible switching between modeling levels is emphasized. Execution of an application program by the architectural and microprogramming level models with switching between levels is illustrated.

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Numerical Method for Computing Nonlinear, Time Dependent, Buoyant Circulation of Air in Rooms *by J. E. Fromm, p. 186.* A method is described which solves the dynamic equations for air circulation at Grashof numbers that are in the range of environmental temperatures of rooms. Previous two-dimensional computation techniques were limited to $G \approx 10^5$ but environmental conditions require $G \approx 10^{12}$. The higher Grashof numbers become calculable through the design of a mixed system of nonlinear difference equations which has purely leading-phase-error properties. In addition provision is made for nonlinear stability by explicitly programming cross derivative terms in lieu of employing "time splitting." The isotropic behavior achieved through time splitting is retained by the system of difference equations. Details of the required algorithms are included.

Random-walk Model of Stream Network Development *by J. S. Smart and V. L. Moruzzi, p. 197.* A random-walk, headward-growth model of stream network development in a region of uniform lithology and uniform slope is proposed. The principal difference from previous models is that the probability of growth is made dependent on the area contributing runoff to the stream tip. Two versions of the model have been studied in detail and shown to give satisfactory results. A major advantage is that all of the important network variables, including drainage density and outlet density, come naturally out of the simulation processes.

Automatic Pulse Parameter Determination with the Computer Augmented Oscilloscope System *by A. A. Guido, L. Fulkerson, and P. E. Stuckert, p. 204.* The Computer Augmented Oscilloscope System (CAOS) is a special computer terminal facility intended for laboratory experiments involving waveforms and their interpretation. The system provides digital acquisition of waveform data, system control and calibration, data analysis, and graphic and alphanumeric display.

Pulse parameter determination requires the use of all system capabilities since a) hardware and software options must be chosen or controlled, b) the pulse waveform must be digitized, c) the appropriate analytical algorithms must be applied to the data and d) the results of analysis must be displayed. Specific attention is given to the algorithms required for pulse parameter determination and a new procedure for determining base and top magnitude of a pulse waveform is presented.

A Quasi-steady-state Analysis for the Electrophotographic Discharge Process *by H. Seki, I. P. Batra, W. D. Gill, K. K. Kanazawa, and B. H. Schechtman, p. 213.* A description of the electrophotographic discharge process is presented for a homogeneous photoconductor characterized by constant free-carrier lifetimes and trapping times. The physical model is described by a set of one-dimensional nonlinear differential equations with appropriate boundary conditions. It is shown that a quasi-steady-state approximation can be derived which is valid for most of the decay process under typical electrophotographic conditions. In this quasi-steady state, the photoconductor layer can be described by an equivalent circuit which consists of a capacitance in parallel with a two-terminal element whose current-voltage characteristic is directly related to the field-dependent photoinjection efficiency. A numerical analysis using large-scale computation of the solutions to the differential equations has been done for a hypothetical but typical material. The results of this computation, which describe the initial transient behavior and the subsequent quasi-steady-state behavior of the photoconductor, are presented. The results of the quasi-steady-state analysis agree with the actual behavior of amorphous Se. It is suggested that measurement of the quasi-steady-state photodischarge process can be used as a convenient technique for obtaining the field-dependent characteristics of the photoinjection process.

Interaction Potential between Li^+ and HD: Region for Rotational Excitation Cross Sections *by W. A. Lester, Jr., p. 222.* The interaction potential between Li^+ and HD (with internuclear separation fixed at 1.4 a.u.) was determined by two different methods using the results of a recent self-consistent-field calculation of the potential energy surface for Li^+-H_2. In one method, Li^+-HD interaction energies were obtained utilizing an analytical representation of the Li^+-H_2 surface. The second method used *ab initio* Li^+-H_2 interaction energies directly to yield the Li^+-HD potential surface by means of interpolation procedures. The interaction potentials determined by the two methods are essentially identical and have been fit to an analytical form, $V(r, \theta) = \Sigma_l v_l(r) P_l(\cos \theta)$, to facilitate scattering studies. For large center of mass distances, perturbation theory is in good accord with the potentials constructed by the two procedures.

A Design Study of Ultrasonic Bonding Tips *by S. Z. Dushkes, p. 230.* The standing wave on ultrasonic bonding tips and the tendency of the lower end to fold back upon itself, termed "lug-down," have been measured under actual bonding conditions. These phenomena have also been modeled on a computer. Lug-down can be a major contributor to bonding failures in designs having an overly slim tip. One definition of a "bonding failure" is the production of a bond between wire and monolithic circuit pad which lifts, when the wire is pulled at 90° to the pad, under a wire tensile force less than 25% of the ultimate tensile strength of the wire. Improper location of nodes can also contribute to bonding failures. A tapered tip has been shown by mathematical analysis to possess a higher resonant frequency and fewer nodes than a tip of uniform cross section. Using the newly developed taper tip, means were found for minimizing lug-down. With judicious trade-offs, it is now possible to optimize tip geometry for a particular bonding application.

Heat-transfer Calculations at the Tape-head Interface of a Computer Tape Drive *by G. M. Lederle, p. 236.* Frictional heat generation can develop localized high temperatures at the tape-head interface of a computer tape drive and can seriously affect the performance of the drive. Using standard heat transfer theory, we calculated the magnitude of this "hot spotting" to be of the order of 21°C for an IBM 2400 series tape drive. In general, it is almost impossible to accurately measure hot spotting on a tape drive. A series of calculations was performed to investigate why this is so.

The Common-core Filter as an Electromagnetic Interference-suppression Device *by D. R. Bush, p. 242.*

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Experimental Fabrication of One-dimensional GaAs Laser Arrays *by J. C. Marinace, p. 258.* Arrays of GaAs injection lasers have been fabricated for use in an experimental EuO film memory system. Planar-type array structures are formed by diffusing zinc through parallel slots in a diffusion mask on

a GaAs wafer. Details of fabrication are given and some initial test results on operating characteristics and life performance are reported.

Fabrication and Properties of Monolithic Laser Diode Arrays *by G. J. Sprokel, p. 265.* Monolithic arrays of planar diffused GaAs injection lasers have been fabricated using diffusion masking and photolithography to delineate the junction area. After contact metallization, the arrays are soldered to a sapphire wafer which serves as a heat sink and carries the contacts for each junction. The diodes operate cw at 78 K and the threshold current density. $J_{th} = 700$ to 1100 A cm^{-2}. The dc power output is linear at least to $5 \times J_{th}$ and the power efficiency, η_P is about 40%. Threshold and power output are quite uniform across the array but the beam polarization varies at random from one unit to the next.

Characteristics of GaAs Laser Arrays Designed for Beam Addressable Memories *by H. Wieder and H. Werlich, p. 272.* Four properties of GaAs laser arrays i.e., the efficiency, junction width, beam spread, and polarization, are important in assessing the usefulness of such devices in beam addressable memory applications. Measurements made on a series of arrays are presented. It is shown that the first two parameters closely approach the characteristics of an idealized array, while the latter two reduce the energy density at the storage plane to 25 percent of that at the junction surface. With existing devices, information has been written and recovered at a bit rate of 10 MHz.

Dynamics of a Flashlamp-pumped Rhodamine 6G Laser *by B. G. Huth and M. R. Kagan, p. 278.* In this paper a rate-equation model is developed for a single-wavelength dye laser. The model is unique in that it accounts for the fact that triplet-state lifetimes are not necessarily very long, as has been previously assumed. This modification makes it possible to analyze more accurately the behavior of dye lasers that are pumped with pulse energies above threshold. Computer solutions of the rate equations are obtained and an experimental technique is developed to measure amplifier gain, which is then used to estimate populations of molecules at various energy levels. An experimental study of triplet lifetimes in anthracene is included in an Appendix. These results support the experimental values obtained by Stockman for Rhodamine 6G, which are used in our calculations.

Interleaving Slow- and Rapid-data-rate Experiments with a Time-sharing Laboratory Automation System *by P. M. Grant, p. 293.* A technique is described for accommodating rapid-transfer-rate experiments within an IBM 1800 Time Share Executive (TSX) laboratory automation monitor designed primarily for slow-scanning, low-drift apparatuses, each having the computer control its independent variable. The slow-scan experiments may be delayed for substantial periods to allow break-in by, and dedication of the computer to, those tasks requiring acquisition of short bursts of high-speed data. The system is structured so that each user can implicitly and dynamically specify the current maximum time interval for which his experiment may be interrupted.

The break-in on a slow-scan experiment is done on a demand-response basis through the use of interrupt coreloads and masking of all other interrupts that are likely to interfere with a particular high-speed scan that has been initiated. When data acquisition is completed, control is returned to the time-sharing system by unmasking the interrupts and an appropriate data analysis task is queued for later execution.

Automation of Data Acquisition in Transient Photoconductive Decay Experiments *by B. H. Schechtman and P. M. Grant, p. 296.* The application of a time-shared IBM 1800 Data Acquisition and Control Computer to data acquisition and reduction in transient photoconductive decay experiments is described. These experiments present an interesting problem in laboratory automation, since they involve high data rates (data periods frequently on the submillisecond scale), a free-running independent variable (time), and a mode of operation in which it is possible to amass large quantities of data in a relatively short time. Techniques are described wherein these transient data are collected in real time while the computer simultaneously monitors many timer-based, slower-scanning experiments. The computer is shown to facilitate a variety of otherwise formidable data manipulation and analysis tasks. In addition to improving the quality of the data obtained, automation of these measurements provides data analysis and display of physical results within minutes after each data logging run, permitting the experimenter to interact closely with the data in a fashion not possible under manual operation.

Automation of a Residual Gas Analyzer on a Time-shared Computer *by D. L. Raimondi, H. F. Winters, P. M. Grant, and D. C. Clarke, p. 307.* The automation of a quadrupole mass spectrometer - residual gas analyzer (RGA) on a time-shared IBM 1800 Data Acquisition and Control Computer is described. The RGA, which is used to determine the partial pressures of various gases in a vacuum system, may be operated up to a maximum data rate of about 20,000 points/sec (pps) in an interleaved manner with multiple slow-scanning (≤ 20 pps) instruments. We review in detail the hardware and software considerations regarding the design and subsequent interfacing of the instrument to the computer. Methods for initiating data collection, entering experimental parameters, and analyzing the experimental data, such as spectrum plotting, smoothing, peak location, mass identification, and calculation of the partial pressures by using a least-squares approximation to fit mass peaks, are discussed with examples.

Equivalent Circuit for Conductivity-Temperature Characteristics of the PdO/Ag-Pd Glaze Resistor *by G. J. Kahan, p. 313.* It is shown that a reasonable fit of experimental to calculated data can be obtained with a simple model of the PdO/Ag-Pd glaze resistor. An equivalent circuit

describing the temperature characteristics of the glaze resistor is proposed. The experimental measurements can be reproduced quite adequately over a considerable temperature range, using an equivalent circuit consisting of a semiconductor contact resistance in parallel with a metal. A quadratic term in $(1/T^2)$ in addition to the usual linear term with $(1/T)$ for $\ln \sigma$ is used to obtain a good fit at low temperatures. (T = absolute temperature; σ = conductivity.) This parabolic curve approaches the experimentally observed values for palladium oxide.

An Improved Method for Designing Optimal Linear Compensators *by S. G. Greenberg and Y. Bard, p. 318.* In linear dynamical systems with white Gaussian plant and observation noise and quadratic cost criteria the well-known separation theorem of stochastic control holds. The result is that the determination of the system matrix for the compensator depends on the solution of two Riccati equations, one arising from a deterministic regulator problem and the other from a filtering problem. It is shown in this paper that if the given system is single-input, single-output and time-invariant, one can achieve substantial savings in computation time. Assuming controllability and observability and using the standard controllable representation of the system matrix, we show that at each iteration step of the solution of the algebraic matrix Riccati equation by Newton's method the number of variables to be solved for reduces from the customary $n(n+1)/2$ to n. Moreover, the number of operations to determine these n variables is on the order of $n^3/16$ as opposed to $n^3/3$ in ordinary matrix inversion.

The observability matrix is used as a similarity transformation so that the Riccati equation for the filtering problem is placed in the same format and the above procedure may be used again. The results obtained are easily extended to the case in which the system is either single-input or single-output. The system matrix of a fifteenth-order compensator was determined using 0.92 seconds of computer time on the IBM System/360, Model 67.

Some Numerical Results for Iterative Continuation in Nonlinear Boundary-value Problems *by W. E. Bosarge, Jr. and C. L. Smith, p. 323.* In this communication we apply certain continuous analog iterative methods to two sample boundary-value problems. We show that the Euler-Newton and the second-order continuation of the Newton method are both useful algorithms for obtaining solutions to classes of nonlinear boundary-value problems. For a convergence analysis we rely upon a number of convergence theorems presented in earlier work. We indicate, through the numerical results, that the relaxed Newton methods are particularly useful in the iterative solution of "strongly" nonlinear problems where little information is available concerning "good starting values."

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Multi-fluid Subdued Boiling; Theoretical Analysis of Multi-fluid Interface Bubbles *by S. Oktay, p. 342.* The recently discovered boiling phenomenon called "multi-fluid subdued boiling" is discussed. It has been observed that when a beaker containing two immiscible liquids of dissimilar densities is heated at the bottom, the vapor bubbles rise in the lower liquid until they reach the liquid-liquid interface. There the bubbles are trapped, and after a short period of time they collapse. As the heat transfer is increased, however, the bubbles begin to coalesce to form a new set of "interface bubbles," and the latter eventually become large enough to break away from the interface and rise into the upper liquid layer. Upon reaching the liquid-air interface most of the bubbles do not escape into the ambient but suddenly condense, contract and drop back toward the lower liquid level. "Boiling off," or net vapor generation, is subdued.

The prediction of the interface bubble sizes is also discussed. Analysis shows that the properties of the fluids used can be included mathematically in nondimensional parainetric forms, by means of which the shapes and sizes of the interface bubbles can be found.

A Procedure for Implementing the Fast Fourier Transform on Small Computers *by J. W. Hartwell, p. 355.* A technique has been developed that adapts the Fast Fourier Transform algorithm for implementation on computers having relatively long multiplication times. The technique is particularly well suited to real-time processing on a small data acquisition computer such as the IBM System/7.

Four basic ideas are utilized to improve the performance of the original Cooley-Tukey algorithm on such a machine:

1) The real-valued nature of the input data is exploited.
2) The number of multiplications that must be carried out is minimized at the expense of additions.
3) The calculations are performed in a carefully ordered sequence.
4) Special multiplication algorithms are used.

This technique has reduced by more than an order of magnitude the time required to carry out 1024-point transformations on a small computer. A program is developed for calculating these transforms in real time on an IBM System/7 computer. With this program, a maximum sampling rate in excess of 10 kHz is obtained.

Generation of Synchronous Data Transmission Signals by Digital Echo Modulation *by M. F. Choquet and H. J. Nussbaumer, p. 364.* This paper shows the basic similarities

among various data transmission techniques. It generalizes the concept of how the signal element serves as a unifying feature of various modulation schemes. The present approach permits an extension of the digital echo modulation technique, originally introduced by A. Croisier and J-M. Pierret, to cover most of the cases of digital data transmission. The practical application of digital echo modulation to the design of modems is discussed and examples of digitally implemented modem transmitters are given.

Activation Energy for Electromigration in Aluminum Films Alloyed with Copper *by M. C. Shine and F. M. d'Heurle, p. 378.* The rate of electromigration in thin films of aluminum and aluminum alloyed with copper has been determined by measuring the changes in resistance of stripes subjected to a current density of 4×10^6 A/cm^2. At temperatures in the range from 100 to 200°C the activation energy for electromigration has been found to have the same value for both the pure and the copper-alloyed samples, namely, 0.6 eV. However, the rate of migration is much smaller, by a factor as large as 100, in the copper-bearing samples. These results are discussed in terms of grain boundary diffusion and the effect of alloying additions on diffusion mechanisms.

Design of Logic Circuit Technology for IBM System/370 Models 145 and 155 *by P. E. Fox and W. J. Nestork, p. 384.* Monolithic System Technology (MST) is a microelectronic circuit family consisting of high-density monolithic circuit chips on ceramic substrates. Using current-switch emitter follower (CSEF) logic, the technology is designed to provide a balanced reflection of cost and performance requirements. One version, MST-2, has been developed for use primarily in the middle range of System/370—the Models 145 and 155. The typical package usually consists of a single multi-circuit chip on a 16-pin module substrate, and the design embodies a number of recent interconnection and packaging developments that make it well suited to large-scale automated production.

The IBM 3803/3420 Magnetic Tape Subsystem *by J. W. Irwin, J. V. Cassie, and H. C. Oppeboen, p. 391.* The design innovations in the IBM 3803 Tape Control Unit and the IBM 3420 Magnetic Tape Unit are discussed. The new design concepts include a full readback parity check, a system of microprogram control that obtains high operating rates through overlap of channel control and motion control functions, a new phase-error detection system, a modified dual-density recording feature and a new interface between the control unit and tape drive. The combination of novel error detection methods, control features and programming support (including an expanded scheme of on-line diagnostics) contributes to greatly improved total system performance over previous models of tape subsystems.

Thermal Problems of the CW Injection Laser *by R. W. Keyes, p. 401.* We describe the theoretical dependence of emitted light power on current in a continuously operating *p-n* junction laser, based on an injection laser model previously developed by the author. The analysis relates power output to threshold current, electrical resistance, thermal resistance, and external quantum efficiency of the laser, all quantities that can be independently measured or calculated for particular structures. The equations presented thus constitute a simple analytical model for both thermal design and diagnosis of operation of cw injection lasers.

Ultra-high-speed Operation of Josephson Tunneling Devices *by H. H. Zappe and K. R. Grebe, p. 405.* Switching times of large Josephson devices have been measured. We report gate switching times of 85 ps and array cycle times of an elementary memory cell of 550 ps. Although these times are expected to be smaller in more realistic miniaturized devices, they represent to our knowledge, the shortest times for such circuits ever reported in any technology.

Synchronization in a Wideband Optical Data Transmission System *by E. M. Philipp-Rutz, p. 408.* An optical synchronization technique is described for the demultiplexer of a wideband optical data transmission system. In this system, the closely spaced optical pulses of interleaved PCM channels are "space sorted" by a coincidence detection technique using an optical reference waveform generated in the receiver. For synchronization of the reference waveform with a spatial waveform produced by the received laser beam in the demultiplexer, a number of pulses on these two optical waveforms are coded with a pseudo-random sequence. Acquisition of the coded waveforms for synchronization is indicated in an optical matched filter. For automatic tracking, a synchronization error-control circuit is added.

Direct Technique for Improving a Matrix Inverse *by G. A. Sitton, p. 413.* A method is shown that transforms the problem of inverting an ill-conditioned matrix to one of inverting a diagonally dominant matrix. An error analysis is outlined and the method is compared in theory and in result with the commonly used iterative methods. This direct method is demonstrated to be the limiting case of an *n*th-order iterative procedure as *n* approaches infinity. Examples are given that show the advantages of the direct method even under adverse conditions. The unreliability of the convergence of the iterative technique due to computational errors is also discussed.

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A Self-Isolation Scheme for Integrated Circuits *by M. B. Vora, p. 430.* A self-isolation scheme is proposed for fabricating transistors in semiconductor integrated circuits. Such integrated circuits with double-diffused transistors require three diffusions and one epitaxial layer in the proposed process. Since no isolation or reach-through diffusions are involved, this technique could reduce the area of a memory or logic cell by 50% or more.

Design and Development of an Ultralow-Capacitance, High-Performance Pedestal Transistor *by H. N. Ghosh, K. G. Ashar, A. S. Oberai, and D. DeWitt, p. 436.*
High-performance transistors with small geometries require a highly doped collector region to produce a large impurity gradient at the collector-base junction. This allows the structure to sustain high current densities and to attain low collector series resistance. However, the resulting increase in collector transition capacitance degrades the ac characteristics of the transistors. A structure is proposed and experimental results are presented in this paper to demonstrate that the conflicting requirements above, which limit the high-performance characteristics of transistors, can be resolved by the planar IC process.

Planar Mesa Schottky Barrier Diode *by N. G. Anantha and K. G. Ashar, p. 442.* Planar silicon technology has been used to fabricate mesa Schottky barrier diodes with high breakdown voltages. This method proves to be superior to alternate methods used to increase the breakdown voltage of Schottky diodes. The processing techniques and characteristics of mesa Schottky diodes are described in this paper.

Electron Beam Fabrication of Micron Transistors *by S. Magdo, M. Hatzakis, and C. H. Ting, p. 446.* For high-speed performance as well as high packing density, it is desirable to make the components in integrated circuits as small as possible. One of the fundamental problems in making smaller components is that of limitations in the optical technology. This paper describes an experimental process and the results obtained by using an electron-optical system to fabricate small transistors. Planar bipolar transistors with emitter and base contact windows one micron wide have been fabricated, with the electron beam exposure system used to open all the diffusion windows as well as to expose the metallization patterns.

Conventional etching techniques are unable to provide 1-μm wide metal paths in half-to one-micron thick metal layers; therefore the lift-off process is used. The dc and ac characteristics presented compare favorably, for the first time using this fabrication process, with the best bipolar transistors produced by optical masking processes. These characteristics provide a guide for refinement in future micron transistor design.

Experimental Evaluation of High Energy Ion Implantation Gradients for Possible Fabrication of a Transistor Pedestal Collector *by J. F. Ziegler, B. L. Crowder, and W. J. Kleinfelder, p. 452.* The use of ion accelerators to implant impurities in crystals has become the subject of widespread research. Such studies have been limited mainly to low energies with acceleration voltages of 50 to 500 kilovolts. In this energy range, impurities are implanted into the upper micron or less of the surface.

The present work describes certain characteristics of high energy ion implantation. The ions used were boron and phosphorus. They were implanted into silicon with energies of 2 to 4 megavolts. In this energy range, the impurities have a useful positive impurity concentration gradient from the surface. The surface concentration is about 4×10^{16} cm^{-3}, and the peak concentration exceeds 10^{19} cm^{-3} depending on dosage. The peak concentration occurs about 2.5 μm deep. After annealing the radiation damage introduced into the semiconductor, it was determined that the surface silicon recovered over 90% of its expected maximum conductivity and mobility.

A discussion is given of the concentration gradients required to fabricate a collector pedestal for a high-speed switching transistor, and it is shown that such gradients can be obtained by using high energy ion-implantation. The pedestal may be implanted after the base and emitter diffusions, and annealed at a low temperature, thus keeping a sharp impurity gradient. Also, since it is put into the final epitaxial layer, its vertical position relative to the emitter-base junction will be independent of epitaxial undulations.

An Arsenic Emitter Structure for High-Performance Silicon Transistors *by H. N. Ghosh, A. S. Oberai, J. J. Chang, and M. B. Vora, p. 457.* Arsenic-doped emitters have been shown to produce high performance in bipolar silicon transistors. In comparison with phosphorus, the emitter dopant commonly used in the industry, the use of arsenic results in a steeper gradient (10^{24}/cm^4), less compensation of the base region, no "emitter dip" effect, and a flatter profile with higher sheet conductivity. Since arsenic atoms are a better match to Si than are phosphorus atoms and the arsenic process requires lower surface concentration for a particular diffusion depth and sheet conductivity, fewer crystal defects are generated. As a result the arsenic emitter process results in a higher device yield and is much more reproducible, even for shallow diffusion depths. Arsenic-emitter transistors, both with and without gold doping, are found to be superior in performance, with 1.6 to 2 times higher gain bandwidth, f_T and current gain, β, than those with phosphorus emitters with similar geometry. Also the ability of the arsenic emitter to sustain large current densities, exceeding 30,000 A-cm^{-2}, makes it extremely desirable for high density, small geometry, and high-performance silicon devices.

Arsenic Source Vapor Pressure Kinetics and Capsule Diffusion *by J. S. Sandhu and J. L. Reuter, p. 464.* After diffusion temperature and time, the most important parameters in capsule diffusion source behavior are the dopant vapor pressure characteristics in the capsule. The vapor pressure behavior is a function of the degree of homogenization of the Si-dopant system and hence of the source preparation technology. Various methods of preparing Si-As source material are discussed. Homogenized-source preparation is described as it relates to reproducibility and controlled capsule diffusion behavior. The measurement of the kinetics of

arsenic vapor pressure development in a typical capsule system and the role of vapor pressure in determining capsule diffusion behavior are described. Finally, the dependence of arsenic vapor pressure characteristics, and hence of the diffusion, on source weight-to-capsule volume ratio is described.

A Diffusion Model for Arsenic in Silicon *by T.-L. Chiu and H. N. Ghosh, p. 472.* It is proposed that double acceptor-level vacancies are responsible for arsenic diffusion into silicon. A computer program, which combines this diffusion mechanism with the formation of arsenic clusters and an internal electric field induced by the impurity gradient, is used to calculate arsenic diffusion profiles in wide ranges of diffusion temperatures and surface impurity concentrations. The calculated diffusion profiles are in good agreement with the measured profiles.

On the Relationship of Resistivity to Arsenic Concentration for Heavily Doped *n*-type Silicon *by T.-L. Chiu and H. N. Ghosh, p. 477.*

Numerical Calculation of Magnetic Fields in the Vicinity of a Magnetic Body *by A. E. Ruehli and D. M. Ellis, p. 478.* Static magnetic fields, resulting from an applied field, are calculated in the vicinity of a magnetic body. Specifically, numerical results are given for a rectangular body of constant permeability. The reduction or shielding of the magnetic fields is calculated in the neighborhood of the body. Integral equations are developed which can be solved numerically on a computer. Typical fields are described for rectangles of different thicknesses, and comparisons with known solutions are shown.

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Silicon Process Technology for Monolithic Memory *by R. H. Collins, E. G. Grochowski, and W. D. North, p. 2.* The successful design and production of high density, high speed monolithic memory circuits that can operate efficiently over wide current ranges can be directly attributed to the development of a new silicon process technology based on the <100> crystal orientation. To provide optimum capability to fabricate these circuits with high yields, process modifications to accommodate larger starting substrates (wafers) have also been adopted. Detailed electrical characterization of the resulting devices has confirmed improved circuit operation, demonstrating that improved gain at low current and good junction quality are consequences of the process modifications.

Design Innovations of the IBM 3830 and 2835 Storage Control Units *by G. R. Ahearn, Y. Dishon, and R. N. Snively, p. 11.* The IBM 2305 Fixed Head Storage and IBM 3330 Disk Storage provide significant performance improvements over previously available disk facilities. Many of the improvements were made possible by the design of the control units, which are complex systems that integrate analog and digital interfaces. Definition of control unit requirements and characteristics permitted a large degree of commonality to be achieved between the two control units. The available design alternatives and implementations are discussed.

Readout Performance Analysis of a Cryogenic Magneto-optical Data Storage System *by B. R. Brown, p. 19.* An analysis of readout signal and noise generation is presented for a magneto-optical data storage system which uses a single laser beam for both Curie-point thermal writing and Faraday readout of magneto-optical films. The analysis is applied to a cryogenic beam addressable file model which utilizes GaAs injection lasers and doped EuO film.

Theories of the Distribution of Deposit from Sputtered Disk and Rectangular Electrodes *by R. E. Jones, Jr., p. 27.* Theoretical expressions for the distribution of deposits sputtered from disk-shaped and rectangular electrodes are derived for cases of 1) uniform emission obeying the cosine emission law, 2) distorted "under cosine" and "over cosine" emission, 3) additional emission confined to the peripheries of the electrodes and obeying the cosine emission law, and 4) distorted "inward" emission from the peripheries.

Cross-coupled Thyristor Storage Cell *by W. Jutzi and C. H. Schuenemann, p. 35.* A symmetrical, cross-coupled, two-thyristor storage cell with 1 μW stand-by power dissipation and 60 nsec switching time is described. When integrated in silicon planar technology each thyristor consists of a vertical *npn* transistor and a lateral *pnp* transistor.

Efficient Evaluation of Array Subscripts of Arrays *by A. Hassitt and L. E. Lyon, p. 45.* The APL language allows subscripted expressions such as $A[I;J;K]$, where A is an array and I, J and K may be scalars, vectors or arrays of any size and shape. We describe an efficient method of evaluating these expressions. The method is quite general and yet it does recognize all the special cases in which multiple subscripts can be reduced to a simpler form. We show how the same mechanism can be used to evaluate other selection operations, such as transpose, and how selection operations may be combined.

Experiments on Page Size, Program Access Patterns, and Virtual Memory Performance *by D. J. Hatfield, p. 58.* The assumption about virtual memory systems that as overhead (time for access and software page management) decreases page size should be reduced is not always a good one. Recent experiments indicate that larger page sizes can provide better performance for programs that make highly localized use of memory space.

Sputter-etching of Heterogeneous Surfaces *by L. I. Maissel, C. L. Standley, and L. V. Gregor, p. 67.* In conventional sputter etching, heterogeneous surfaces are eroded at generally unpredictable rates. The reasons for this are discussed and a solution to the problem is given: Based on control of redeposition, the technique involves the use of a device called a "catcher," which is placed near the target of the sputtering chamber to trap re-emitted particles. Experiments are described which confirm the effectiveness of the approach.

Ge Epitaxial Refill Deposition Techniques for Fabricating Pedestal Transistor Structures *by V. J. Silvestri, T. B. Light, H.-N. Yu, and A. Reisman, p. 71.* An etch-epitaxial refill technique is described for the fabrication of integrated high-speed Ge transistor structures having a pedestal configuration. The device areas surrounding 0.1 ohm-cm mesa structures were refilled with Ge having a resistivity range of 1 to 10 ohm-cm, providing low parasitic capacitance in the passive area of the base-collector junction. Processes and techniques were developed for minimizing the ridge that tends to form at the edge of the deposited SiO_2 mask. Electrical properties and junction characteristics of the epitaxial regions are discussed and some device results presented.

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Model for Time-dependent Raindrop Size Distributions; Application to the Washout of Airborne Contaminants *by F. F. Abraham, S. K. Jordan, R. N. Kortzeborn, and H. G. Kolsky, p. 91.* We have developed a model for computing time-dependent behavior in raindrop size distributions for a variety of initial conditions. The model permits the inclusion of a spatially varying atmospheric profile and takes evaporation and coalescence of raindrops into account on a dynamic basis. We have applied this model to the washout process by rain, whereby small airborne particles are scavenged below a rain cloud. In comparing our results with

those of previously published time-independent models, we found that the time-dependent effects greatly altered washout at lower elevations.

Rationale, Limitations, and Assumptions of a Northeastern Forest Growth Simulator *by D. B. Botkin, J. F. Janak, and J. R. Wallis, p. 101.* A cooperative agreement between Yale University and the 1970 summer program of the IBM Research Division resulted in a flexible computer program to simulate the growth of the uneven-aged, mixed-species stands of trees on the 10-meter by 10-meter experimental plots of the Hubbard Brook Ecosystem Study in the White Mountains of northern New Hampshire. Annual increments of tree growth are based on species, tree size, and allocation of available light among the competing trees of the plot. Site quality differences between plots are assigned primarily by the concept of tree-growing degree-days, although soil moisture storage during the growing season and plot rockiness are also considered. Species succession, individual tree suppression and release, and other dynamic properties of forest stands have been successfully reproduced using the program. Additional field measurements are needed to further verify the model and to extend its applicability to nutrient cycling and other aspects of the Hubbard Brook Ecosystem Study. We believe that the simulator could readily be extended to include most other tree species of northeastern North America and also to match data from other sites through appropriate adjustment of program parameters.

Subsurface Hydrology at Waste Disposal Sites *by R. A. Freeze, p. 117.* One result of the growing concern over surface-water pollution has been an increase in the popularity of ground-based waste disposal practices that save the streams but have a high potential for subsurface pollution. One of these, sanitary landfill, appears quite promising in its ability to handle large waste loads with a minimum of contamination; but two others, waste lagoons and deep-well injection of liquid wastes into geologic formations, lead to irreversible subsurface pollution. In all cases, the mechanism of pollution is an interaction between the pollutant source and the existing soil-moisture and groundwater flow systems. A mathematical model of the subsurface flow can be used to predict this interaction and to assess the impact on the environment of a proposed disposal site. The model applied in this paper can predict transient and steady state subsurface flow systems in two or three dimensions and includes consideration of both the saturated and the unsaturated zones. It can be applied at the reconnaissance stage on a regional basis to analyze a large number of alternative sites and at the chosen site to test the efficiency of various design alternatives and to provide guidance in the design of a monitoring system. The model predicts only convective transport and does not consider dispersion or hydrochemical reactions.

Estimate of Subsidence in Venice Using a One-dimensional Model of the Subsoil *by G. Gambolati, p. 130.* This work applies a one-dimensional model, based on K. Terzaghi's theory of vertical consolidation, to the calculation of land subsidence in the Venetian Lagoon, caused by extraction of water from artificial wells. Certain assumptions are made in order to compensate for the scarcity of data currently available, and these are discussed with regard to both the geophysical characteristics of the subsoil and the decline in piezometric level in the various strata. The interpretation of the results shows a direct correlation between water extraction and surface subsidence.

Nonsupervised Crop Classification through Airborne Multispectral Observations *by G. Nagy and J. Tolaba, p. 138.* Current methods of terrain classification by means of airborne multispectral observations are reviewed with emphasis on the selection of training sets for determination of the categorizer parameters. A method of selecting sample regions for assigning identities to the spectral signatures on the basis of statistically determined similarities, rather than on *a priori* considerations, is suggested. This method has been tested on data collected on two flights with the University of Michigan scanner over an agricultural region in California. We have found that a simple clustering algorithm, modified to take into account specific features of the crop-census problem, can be used to obtain the desired homogeneous regions with relatively little computation and that very sparse sampling of these regions is sufficient to assign the appropriate category to each cluster. Viewed as a two-stage sampling procedure, clustering improves the second stage classification on 15 crops from 20 to 50 percent over a random selection of the primary sampling units. The accuracy increases to 73 percent when only five classes are considered, with further improvement to 88 percent when a majority decision based on known field boundaries is used.

Interactive Computer-based Game for Decision-making in Ecology *by T. I. Peterson and P. N. Wahi, p. 154.* This paper describes a prototype Ecology Decision Game which has been developed for experimental use within IBM. The paper is directed to those in ecology desiring to use similar techniques in developing programs that interrelate computing, management science, mathematics, and APL for training and educational purposes. The game is implemented in two modes: an *author* mode, which permits an author to write his own scenario; and a *player* mode, which enables a person to play the game. Features of the game exploit interactive capabilities for both modes. The particular scenario written for the game treats decision-making in the environmental area of solid-waste management. Three submodules explore progressively more complicated situations that give rise to management science problems: shortest route, transportation, and maximal flow. By active and passive role-playing, and controlled and uncontrolled learning, the player is given the opportunity to use quantitative tools to refine his subjective judgments.

Air Quality Diffusion Model; Application to New York City *by L.-J. Shieh, P. K. Halpern, B. A. Clemens, H. H. Wang,*

and F. F. Abraham, p. 162. An experimental multisource air pollution diffusion model based on the Gaussian plume formulation is described. The model incorporates point and area sources, time and space dependence of source strengths, and time and space dependence of meteorological variables. Numerical simulation of the SO_2 concentration distribution for New York City on January 11, 1971, agrees favorably with experimental measurements.

Numerical Investigation of the Atmospheric Dispersion of Stack Effluents *by C.-C. Shir, p. 171.* This report describes a numerical method based on the best gradient-transfer theory currently available for computing pollutant concentration distributions downwind from a stack. The vertical inhomogeneity of the atmosphere and ground roughness are included in the model. Vertical wind and temperature profiles are calculated numerically from given values of ground roughness and wind speed and relative temperature at stack height. An equation governing the plume from the stack is solved by a finite difference method. The numerical results, compared with several experiments, suggest that ground roughness is an important parameter and that disagreement between different sets of experimental data may be due to different values of this parameter. The effect of wind is found to be small under neutral conditions. The effective mean wind decreases to a minimum value a short distance from the stack and then increases downwind.

Appendix—Three-dimensional interpretation of the two-dimensional advection-diffusion equation *by W. E. Langlois, p. 178.*

Overlap Emissivity of CO_2 and H_2O in the 15-μm Spectral Region *by N. Braslau, p. 180.* Radiative transfer in model atmospheres including CO_2, water vapor, ozone, and clouds can be explored by computer simulation for the purpose of predicting the mean temperature at the surface of the earth. Where two or more gases have overlapping absorption lines, the overlap emissivity determined from the band-averaged expressions is a possible source of uncertainty. This method has been tested in a 250-cm^{-1} region around 15 μm where the CO_2 absorption overlaps the tail of the water vapor rotation band. Published high resolution spectra of these gases enable the overlap effects to be calculated for small spectral intervals and summed over the band. This calculation was made and compared with the value given by the approximate treatment for the same gas concentrations, pressure, and temperature. Agreement was within 10 percent, indicating that the more detailed spectral calculation is unnecessary.

A Model of Charge Transfer in Bucket Brigade and Charge-coupled Devices *by L. G. Heller, W. H. Chang, and A. W. Lo, p. 184.* Investigation of bucket brigade (BB) and charge-coupled devices (CCD) has resulted in the development of a general model for these devices and their various modes of operation. Similarities and differences between BB and CCD are discussed. The nonlinear partial differential equation of charge motion composed of self-induced drift, thermal diffusion, and electrode fringe-field terms is used to study CCD numerically. The factors that affect charge transfer are investigated by varying the stored charge density, the device length, the transfer-gate-to-storage electrode voltage, and the fringe field. The results include several plots of charge transfer vs time.

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Preface: Mechanical Technology *by J. L. Hibbard, p. 202.*

Mechanics of Film Adhesion: Elastic and Elastic-Plastic Behavior *by W. T. Chen and T. F. Flavin, p. 203.* A peel test is a useful method for comparing the behavior of various adherends and adhesives. An exact analysis of the mechanics of the peel test would be of great help in the interpretation of test results in terms of the bulk properties of the materials, and of the failure mechanism of the bond. The existing theories of peeling apply to *elastic* peel films, *very thin* elastic or viscoelastic adhesive, and a *rigid* substrate. In many applications the film is metallic, stressed beyond its elastic range; the elasticity of the substrate is often similar to that of the adhesive; and the adhesive may be quite thick compared to the film, or may be wholly absent as in electroplated components. In this paper, the effects of non-elastic behavior of the film are analyzed. Results from the use of computer programs that incorporate an analytical model of steady state peeling are presented and compared with experimental data.

Viscoelastic Behavior of Computer Tape Subjected to Periodic Motion *by G. W. Baumann, p. 214.* The purpose of this study was to develop a theoretical means for predicting the longitudinal motion of computer tape in a high-performance tape drive. In particular, this paper treats the motion that is governed by traveling velocity-stress wave reflections, attenuations, and interactions in the length of tape between the tangency point at the capstan and the tangency point at the stubby column in the drive.

The motion of the tape was determined by solving the classical, damped, one-dimensional wave equation subject to the appropriate boundary conditions. J. C. Snowdon's low-damping constitutive model was used to describe the viscoelastic behavior of the tape. The solutions for simple boundary conditions were experimentally verified by mechanical impedance techniques. More complex boundary conditions, such as those for vacuum columns, were experimentally studied to determine the true mathematical boundary conditions.

This paper also discusses simple unreflected harmonic waves, simple reflected harmonic waves, and general periodic reflected waves as examples. The significance of the wave interactions in the design of tape drives is considered.

Dynamic Control of Spring-driven Mechanisms *by R. E. Bishop and C. C. Wilson, p. 222.* A common method for moving a machine member from one position to another is the use of a spring. Spring-driven devices are simple, inexpensive, and easy to implement; however, the velocity characteristics of such devices leave much to be desired. The velocity increases from the initial position to the final position resulting in a maximum velocity, and therefore maximum energy in the mechanism, at the final position. The simplest method of stopping the device, a rigid stop, results in high impact forces and undesirable noise. Many methods have been developed for limiting the velocity of spring-driven mechanisms, such as the centrifugal friction brakes used in telephone dials and fans used in music boxes. Other approaches such as dashpots or shock absorbers have been used to decelerate devices. This paper discusses a method for both velocity control and deceleration by the use of a single pneumatic cylinder. In addition, a method of reducing velocity variability due to differences among the work functions of the mechanism is described, and the application of such a device to a paper-cutting mechanism is presented. The concepts and theory presented are general and therefore apply to the entire class of spring-driven mechanisms.

IBM Copier Scanning System *by D. A. Beaty, T. A. Hoskins, T. H. Richards, and H. W. Simpson, p. 231.* The quality of the copy to be produced by the IBM Copier was of utmost importance in the machine development. This dictated that the amplitude of the vibrations of the document scanning system during scan be limited to a very low level. The design considerations, analysis, simulation, and instrumentation used to assure adequate performance of the system are described.

Some Design Considerations for a Document Sorting Machine *by J. L. Zable and J. C. Yarrington, p. 239.* A document reader-sorter is analytically studied to determine the effect of document velocity on the number of documents that can be sorted reliably in a given interval of time, and a formula is derived that relates the effect of various design parameters to the throughput of a document sorting machine. One of these parameters, selector response time (i.e., indexing time), is investigated in detail. Both analytical and graphical design techniques are developed to minimize the response time of the selector. These techniques, which are explained by simple examples, are quite general and can therefore be applied to many other incrementing devices.

Acoustic Signal Analysis for Noise Source Identification in Mechanisms *by R. H. Peterson, A. D. Ackerman, and R. E. Zelenski, p. 249.* Proper interpretation of the time and frequency characteristics of machine noise provides information useful in identifying and quantifying noise sources in complex mechanisms. The use of commercial acoustic instrumentation led to the development of unique analog instrumentation for noise-time analysis and ultimately to a real-time analog-digital signal analysis capability. The hybrid system described in this paper provides the time and frequency resolution necessary for noise source identification and evaluation.

Holographic Interferometry Deformation Study of a Printer Type-piece *by A. D. Wilson and D. H. Strope, p. 258.* Holographic interferometry with a pulsed ruby laser is used to determine printer type-piece deformation caused by impact of the print hammer. A variety of type-piece designs are examined. Effects of impact velocity and hammer-type-piece alignments are studied. Means of obtaining stress information from the holographic data are considered. Cubic spline methods are used to smooth the holographic data and to obtain continuous first and second derivatives. The stresses calculated from the holographic data agree well with those obtained by other means such as finite element analysis. Some limitations of the holographic technique as well as its advantages are discussed.

Considerable type-piece twisting is observed; this was not expected or known previously. The most significant result is that a type-piece tends to twist when impacted by the hammer at any point other than the exact center. The twist angle is of the same magnitude as the angle of out-of-plane motion of the type. Hence the type may impact the platen on one corner or side edge. Also, the type bends greatly in the necked down region adjacent to the character and does not pivot by a large amount at its bearing point. Twisting motion is propagated from one end of the type to the other.

An Application of White Light Interferometry in Thin Film Measurements *by C. Lin and R. F. Sullivan, p. 269.* An application of the white light interferometry technique has been developed for measuring the thickness of thin films. The technique is used in the development of sliders which serve as carriers for the magnetic transducers (read/write elements) that operate in close proximity to magnetic disks. With the proper design of a surface contour and the applied load on the slider, a self-acting air bearing is created under the slider due to the boundary layer existing on a rotating disk.

To evaluate the performance of these sliders, parameters such as surface contour and steady-state slider-to-disk spacing must be determined. Since these parameters have a magnitude of only a few wavelengths of visible light, a light interference technique was chosen for their measurement. Conventionally, measurements of this kind are made with monochromatic light. However, when measurement magnitudes are less than 1 μm, the resolution of white light interferometry surpasses that of the monochromatic technique.

The white light interference pattern is a continuous color spectrum instead of the dark and bright fringes of the monochromatic technique. For a film thickness of less than 1 μm these colors can be identified to a resolution of 0.05 μm, as compared with 0.15 to 0.20 μm for the visible monochromatic fringes of the technique currently applied to the measurement of these parameters.

Removal of Numerical Instability in the Solution of Nonlinear Heat Exchange Equations *by J. W. White, p. 277.* Current relaxation methods used by most large-scale thermal-computation programs for solving steady-state temperature distributions are subject to numerical instability when radiation is present in the system under study. The instability is usually due to the linearization of the numerical formulation of the governing equations and manifests itself as an oscillatory or divergent solution. A new method of solution is presented, which takes advantage of the diagonal dominance of the coefficient matrices of the linear and nonlinear transfer modes and uses a Gauss-Seidel system relaxation method together with a Newton-Raphson root-evaluation technique. System solution appears similar to that for a diagonally dominant linear system for all magnitudes of radiation. Test cases show the method to be monotonically convergent over the entire range of the radiation parameter considered, while previous methods were found to fail at certain magnitudes of the nonlinear term.

Design and Fabrication of Heat Transfer Surfaces from Superplastic Material *by J. B. Randolph and F. K. King, p. 283.* The production of complex heat transfer surfaces (i.e., those without straight fins) is restricted by available fabrication techniques, materials, geometries, and cost. Based on the superplastic sheet thermoforming process, a new technique for fabricating these complex surfaces by a relatively simple, low cost process has been developed. The resulting surfaces have excellent heat transfer characteristics and can be used in a wide variety of applications. Surface design is discussed, and heat transfer and flow friction test data on various surface patterns are presented. The application of these results to unique design situations is demonstrated and particular examples are discussed.

Stationary Temperature Profiles and Heat Flux Distribution in a Plastic-encapsulated Circuit Package *by J. A. Paivanas, p. 292.* Thermal characteristics that are important to structural integrity are analyzed herein for a TTL, plastic-encapsulated package. By assuming that total module heat during operation is engendered at idealized junctions between lead wires and the chip surface, an analysis of its dissipation has been undertaken to determine internal steady-state temperature profiles and heat flux distribution. Based on junction heat sources of equal strength and on certain adiabatic assumptions, the multi-wire package has been modeled as a single-wire "composite" incorporating postulated heat dissipation mechanisms in representative plastic-to-wire and chip-to-lead frame thermal circuits. These circuits are treated, respectively, by axisymmetric and one-dimensional analyses. Instead of a partial differential equation approach in the former treatment, a less complicated method is devised which leads to characterization by a pair of linear ordinary differential equations. Their closed-form solution gives expressions for calculating two-dimensional temperature profiles and heat flux fractions. The resultant analyses are applied to a module containing 14 lead wires and operating at a given power level. The plastic and wire temperature profiles are seen to be nonlinear in the neighborhood of the chip surface and to coalesce axially into a common, essentially linear form in the outlying regions of the module. Constituent heat fluxes are also calculated for each thermal circuit, and some implications of the overall results to thermal stress are qualitatively discussed.

Analytical and Experimental Thermal Analysis of Multiple Heat Sources in Integrated Semiconductor Chips *by R. D. Lindsted and D. A. DiCicco, p. 303.* Because of the complexity and interconnection density of today's integrated circuit chips, experimental measurement of individual transistor or diode junction temperatures under typical powered conditions has become increasingly difficult. In order to provide meaningful thermal data, other approaches have had to be devised. In the work described by this paper, an analytical model has been used to determine the steady state junction temperature rise on an integrated circuit chip. The effect on junction temperature of heat source size, geometry, and number of adjacent heat sources has been studied. Experimental testing on specially prepared chips has verified the analytical results.

Monitoring Microinch Displacements in Ultrasonic Welding Equipment *by F. J. Crispi, G. C. Maling, Jr., and A. W. Rzant, p. 307.* This communication describes two non-contacting techniques for dynamic measurement of high frequency microinch displacements, which have been applied in monitoring the dynamic displacement of the magnetostrictive transducer system used in ultrasonic welding. One technique consists of a light reflecting scheme that uses a fine fiber optic probe. The probes are available in a range of sizes and, in general, can be used to measure displacements of from zero to 0.030 in. at low frequencies and from 5 to 5000 μin. at any frequency below 100 kHz. The second method, an acoustical technique, leads to results similar to those obtained with the reflective system and can be used with a 0.030-inch diameter acoustic probe; this technique has been used in a frequency range well above that usually associated with probe tube measurements.

Design Considerations for a Magneto-optic Cryogenic Film Memory *by A. M. Patlach, p. 313.* It has been shown that certain materials, because of their ability to rotate the polarization vector of plane polarized light, can be applied to very large data-stores. One such material (iron-doped europium oxide) requires an operating temperature below 100 K. To produce an experimental device with superior cost/performance, a rotating disk file configuration was chosen. In developing this machine there were many unique demands placed on bearing technology, vacuum technology and system configuration. These and some material considerations, as well as the novel engineering features, will be described.

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Preface: Mathematics of Numerical Computation *by S. Winograd, p. 334.*

***A*-stable, Accurate Averaging of Multistep Methods for Stiff Differential Equations** *by W. Liniger and F. Odeh, p. 335.* Several low-order numerical solutions of stiff systems of ordinary differential equations are computed by repeated integration, using a multistep formula with parameters. By forming suitable linear combinations of such solutions, higher-order solutions are obtained. If the parameters are properly chosen the underlying solutions, and thus the higher-order one, can be made *A*-stable and strongly damping with respect to the stiff components of the system. A detailed description is given of an algorithmic implementation of the method, which is computationally efficient. Numerical experiments are carried out on some test problems, confirming the validity of the method.

Hopscotch Difference Methods for Nonlinear Hyperbolic Systems *by A. R. Gourlay and J. L. Morris, p. 349.* In a recent series of papers, one of the authors has developed and demonstrated properties of a computational algorithm for solving partial differential equations. This process, known as the hopscotch algorithm, has been studied particularly with reference to the efficient integration of parabolic and elliptic problems. In the present paper attention is directed to the application of the technique to the numerical integration of first-order nonlinear hyperbolic systems. While maintaining the properties of the hopscotch process as applied to parabolic problems, it is shown that one of the novel schemes generated by this approach has an added bonus, namely, maximum stability for a variable choice of damping or pseudoviscous term. This property should be of particular value in the solution of problems with shocks. A class of hopscotch Lax-Wendroff schemes is also studied.

Parallel Shooting Method for Boundary-value Problems: Application to the Neutron Transport Equation *by J. Canosa and H. R. Penafiel, p. 354.* A direct method is given for the solution of the spherical harmonics approximation to the Boltzmann equation for neutron transport in slab geometry. The roundoff instability of the problem is eliminated by performing linear transformations of the matrices involved, which ensure that the matrix columns are linearly independent. The novelty of the method lies in that only a minimum number of matrix transformations is performed, the precise number being determined dynamically, efficiently, and in a new way by the program itself in the course of the computation.

Finite Difference Formulas for Neumann Conditions on Irregularly Shaped Boundaries *by L. E. Alsop and A. S. Goodman, p. 365.* A method, based on finite element techniques, is described for obtaining finite differences for Neumann conditions on irregularly shaped boundaries. The resultant difference equations may be used in both time-dependent and -independent problems. As an example, the propagation of an elastic surface wave (Rayleigh wave) around a 90° corner is studied. The results of this simulation compare favorably with laboratory experiments.

Turán Formulae and Highest Precision Quadrature Rules for Chebyshev Coefficients *by C. A. Micchelli and T. J. Rivlin, p. 372.* Expansions of functions in series of Chebyshev polynomials are frequently used in numerical analysis. The coefficients occurring in the expansion are definite integrals; the purpose of this paper is to investigate numerical integration formulae for the coefficients of highest degree of precision.

Automatic Computation of Exponentials, Logarithms, Ratios and Square Roots *by T. C. Chen, p. 380.* It is shown how a relatively simple device can evaluate exponentials, logarithms, ratios and square roots for fraction arguments, employing only shifts, adds, high-speed table lookups, and bit counting. The scheme is based on the cotransformation of a number pair (x,y) such that the $F(x,y) = f(x_0)$ is invariant; when x is driven towards a known value x_0, y is driven towards the result. For an N-bit fraction about $N/4$ iterations are required, each involving two or three adds; then a termination algorithm, based on an add and an abbreviated multiply, completes the process, for a total cost of about one conventional multiply time. Convergence, errors and simulation using APL are discussed.

Enveloping an Iteration Scheme *by W. L. Miranker, p. 389.* The problem of determining the optimal values of relaxation parameters for a linear iteration is solved. The optimal iteration scheme is achieved by a second-order linear iteration method.

Numerical Properties of a Multivariate Ritz-Trefftz Method *by W. E. Bosarge, Jr. and C. L. Smith, p. 393.* In this paper the numerical properties of the Ritz-Trefftz algorithm are discussed in the context of the numerical approximation to the linear parabolic regulator problem using multivariate splines. The algorithm is first derived in the problem context and the resulting linear algebraic system is discussed. Such properties as definiteness and band structure are treated. The algorithm is applied to a number of sample control problems, and it is shown that the method yields efficient and highly accurate continuous approximations to the solutions of the selected sample problems. Computer implementation of the general algorithm is also discussed.

Recursive Evaluation of Padé Approximants for Matrix Sequences *by J. Rissanen, p. 401.* An algorithm is described for calculating the existing Padé approximants to any sequence $A_0, A_1, \ldots$ of $s \times t$-matrices. As an application the algorithm gives a new way for finding the minimal polynomial of any square matrix A and the inverse of the characteristic matrix $xI-A$.

On the Convergence of Gradient Methods under Constraint *by P. Wolfe, p. 407.* The mathematical programming problem discussed is the convergence of a certain popular type of gradient procedure for maximizing a function under inequality constraints. An example shows that convergence to a solution need not always occur, and a theorem shows that under certain circumstances the gradient method does converge.

Finding All Shortest Distances in a Directed Network *by A. J. Hoffman and S. Winograd, p. 412.* A new method is given for finding all shortest distances in a directed network. The amount of work (in performing additions, subtractions, and comparisons) is slightly more than half of that required in the best of previous methods.

Maintaining a Sparse Inverse in the Simplex Method *by J. A. Tomlin, p. 415.* Improved methods are discussed for handling sparse matrices in practical linear programming. An analytical comparison is made of four methods for updating the inverse in the iterations following a reinversion. Of these, one technique using the elimination form of inverse is selected for some computational experiments and its advantages in terms of speed and sparseness demonstrated.

Mixed-integer Algorithms for the (0,1) Knapsack Problem *by M. M. Guignard and K. Spielberg, p. 424.* An enumerative scheme is presented for the (0,1) knapsack problem as a specialization of the state enumeration method. Techniques are explored for rendering search procedures more efficient by systematic use of information generated during execution of the algorithm. The inequalities of Benders and Gomory-Johnson are exploited to yield implicit enumeration tests in the special case of the knapsack problem. In a comparative study of eight algorithms and of the utility of certain approximations and inequalities, computational results are given for twelve knapsack problems, each having ten (0,1) variables. The effectiveness of these enumerative algorithms are thus tested in a relatively simple framework.

Linear Convergence of the Conjugate Gradient Method *by H. P. Crowder and P. Wolfe, p. 431.* There are two procedures for applying the method of conjugate gradients to the problem of minimizing a convex, nonlinear function: the "continued" method, and the "restarted" method in which all the data except the best previous point are discarded, and the procedure is begun anew from that point. It is demonstrated by example that in the absence of the standard initial starting condition on a quadratic function, the continued conjugate gradient method will converge to the solution no better than linearly. Furthermore, it is shown that for a general nonlinear function, the nonrestarted conjugate gradient method converges no worse than linearly.

On the Davidenko-Branin Method for Solving Simultaneous Nonlinear Equations *by R. P. Brent, p. 434.* It has been conjectured that the Davidenko-Branin method for solving simultaneous nonlinear equations is globally convergent, provided that the surfaces on which each equation vanishes are homeomorphic to hyperplanes. We give an example to show that this conjecture is false. A more complicated example shows that the method may fail to converge to a zero of the gradient of a scalar function, so the associated method for function minimization is not globally convergent.

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Combinatory Programming and Combinatorial Analysis *by W. H. Burge, p. 450.* The principal purpose of this paper is to illustrate by means of simple examples a technique for deriving programs and generating functions from set descriptions. The paper discusses certain interesting correspondences among types of trees, which follow from the use of the technique, and it demonstrates close connections between programming techniques and some aspects of combinatorial theory.

Recursive Computational Procedure for Two-dimensional Stock Cutting *by J. C. Herz, p. 462.* A recursive algorithm is implemented to give high computational speeds in the solution of a cutting-stock problem. Optimal edge-to-edge cutting is shown to be achieved more easily by recursive programming than by conventional methods. The technique features preliminary discretization, which lowers the memory requirements in the computational procedure. A comparison is made between this recursive algorithm and two iterative algorithms previously given by Gilmore-Gomory. The limitations of the algorithms are discussed and some numerical results given.

Inductance Calculations in a Complex Integrated Circuit Environment *by A. E. Ruehli, p. 470.* This paper describes a method for calculating multiloop inductances formed by complicated interconnection conductors. Knowledge of these inductances leads to useful information concerning the design of such systems. In the approach pursued here, the conductor loops are divided into segments for which so-called partial inductances are calculated. The partial inductances are then appropriately added to yield the desired loop inductance.

Existence and Uniqueness of the Solution to Holland's Equations for a Class of Multicolumn Distillation Systems *by D. S. Billingsley, p. 482.* The Holland equations for a multiunit system of distillation columns, interconnected so as to contain recycle loops, can be expressed as a matrix generalization of the Holland equations for a single complex column. Proof of the existence and uniqueness of a positive solution for the single-column case has previously been given. In this paper a proof is given for the case of a multiunit system containing one recycle loop.

Compiling Optimized Code from Decision Tables *by H. J. Myers, p. 489.* This paper reviews the structure of decision

tables and methods for converting them into procedural code. It describes new optimization methods, which are applied before, during, and after code generation. Some results from an experimental decision table processor are provided.

Widely Convergent Method for Finding Multiple Solutions of Simultaneous Nonlinear Equations *by F. H. Branin, Jr., p. 504.* A new method has been developed for solving a system of nonlinear equations $g(x) = 0$. This method is based on solving the related system of differential equations $dg/dt \pm g(x) = 0$ wherein the sign is changed whenever the corresponding trajectory $x(t)$ encounters a change in sign of the Jacobian determinant or arrives at a solution point of $g(x) = 0$. This procedure endows the method with a much wider region of convergence than other methods (occasionally, even global convergence) and enables it to find multiple solutions of $g(x) = 0$ one after the other. The principal limitations of the method relate to the extraneous singularities of the differential equation. The role of these singularities is illustrated by several examples. In addition, the extension of the method to the problem of finding multiple extrema of a function of N variables is explained and some examples are given.

Detection of Discontinuities in Passivating Layers on Silicon by NaOH Anisotropic Etch *by I. J. Pugacz-Muraszkiewicz, p. 523.* Discontinuities in glasses deposited on silicon substrates are readily detected by a silicon-preferential etch that uses single component alkali solutions. The etchants can be applied to thermally gown oxide films, pyrolytically-deposited passivating layers or sputtered quartz. The character of the discontinuities in these films is shown and the size can be estimated (although both observations are subject to the limitations of the optical tools used for observation or micrography). When applied in the temperature range below +70°C, the etchant attacks the oxides insignificantly and the concentration, as well as the temperature, is chosen for convenience. Above +70°C the passivating layers, particularly thermal SiO_2, are etched at higher rates, and the etching effects must be taken into account if the oxide thickness is less than 1000 Å. The etchants are applicable to intrinsic as well as extrinsic silicon up to a doping level of 10^{20} cm^{-3}.

Nuclear Backscattering Analysis of Nb-Nb_2O_5-Bi Structure *by J. F. Ziegler, M. Berkenblit, T. B. Light, K. C. Park, and A. Reisman, p. 530.* The technique of nuclear backscattering has been used to analyze the interface reactions of Nb-Nb_2O_5-Bi multilayer films. This new analytical technique is explained in detail. It has been concluded that the drastic and erratic changes in the electrical properties of niobium oxide switchable resistor devices that take place at 450°C are associated with the gross migration of oxygen from the oxide to the niobium layer. The accompanying reactions of bismuth with the oxide are relatively moderate, diffusing less than 3×10^{11} atoms/cm^2 of bismuth into the oxide layer.

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Theory on the Speed of Convergence in Adaptive Equalizers for Digital Communication *by G. Ungerboeck, p. 546.* This paper presents an analysis of the convergence properties of adaptive transversal equalizers minimizing mean-square distortion. The intention is to reveal the influence on the speed of convergence exerted by the number of taps, the step-size parameter in the adjustment loops, and the spectrum of the unequalized signal. Attention is focused on the convergence of the expected mean-square distortion. Several approximations are made in the analysis, among them the approximation of higher-order statistics by second-order statistical parameters. Comparison with results obtained by computer simulation, however, shows that the theory developed renders a quite accurate picture of the convergence process.

Previous work in this field demonstrated the limits set to the speed of convergence by the extreme values of the power spectrum of the unequalized signal. It is shown here that, with regard to the mean-square distortion, the influence of the number of taps will usually dominate by far. The theory provides a simple criterion for convergence and answers the question of how to attain the fastest convergence.

A New Class of Automatic Equalizers *by R. T. Sha and D. T. Tang, p. 556.* A new class of automatic equalizers with very fast convergence is discussed in this paper. This fast convergence is accomplished by means of an iterative procedure which successively makes higher-order approximations on the desired equalizer function. The iterative procedure can be conveniently realized in the form of transversal filter stages in cascade. For a given distortion $D < 1$, the residual distortion at the equalizer output after n iterations can be reduced to no more than D^{2^n} in the noise-free cases. When this approach is applied to the feed-forward part of a recursive structure, the front distortion (due to precursors) can be reduced in a similar fashion without unduly increasing the overall distortion. The resulting distortion, mainly in the rear end, can then be cancelled out via feedback paths. Other topics treated include certain generalizations, the truncation error due to limited length in cascaded equalizer sections, and the effect of noise. Several numerical examples are also presented to illustrate the effectiveness of the approach.

Computational Model of a Closed Queuing Network with Exponential Servers *by F. R. Moore, p. 567.* A simplification and extension to Gordon and Newell's approach to closed queuing networks is derived. The equations, valid for exponential servers, with one server being a multiserver, greatly reduce the computation time required by the former approach. In addition, simplified equations for the details of the queuing network are derived.

Exact Implicit Enumeration Method for Solving the Set Partitioning Problem *by P. Michaud, p. 573.* The

partitioning problem may be stated as follows: Minimize $\sum_{j=1} c_j x_j$ subject to $\sum_{j=1} a_{ij} x_j = 1$, $i = 1, ..., m$,

where a_{ij} and x_j are binary numbers.

The proposed method consists in solving a new problem equivalent to the original one, the solution of this new problem being obtained by implicit enumeration. Computational experience indicates that this approach yields good results; for example, problems involving several hundred variables were solved in a few seconds.

Optimum Storage Allocation for Initial Loading of a File *by J. A. van der Pool, p. 579.* When a file is loaded into a direct access storage device using key-to-address transformations, the number and size of storage blocks can be selected. In this study, a selection that minimizes the combined cost of storage space and accesses to the storage device is determined for the case where no record additions or deletions occur after loading.

The analysis is based on the assumption that for a given set of keys, a transformation exists that gives a uniform probability distribution over the available addresses. Under this assumption, formulas are derived for the average number of overflow records and for the average number of accesses required to retrieve a record.

Given these formulas, the costs are expressed as a function of storage used, number of accesses, cost per unit of storage, and cost per access. Minima are computed for a range of block sizes and operational conditions. The results seem to indicate that current file design practices are abundant with storage space.

Finally, the results are condensed in an easy to use approximate formula.

Magnetic Bubble Memory Organization *by W. F. Beausoleil, D. T. Brown, and B. E. Phelps, p. 587.* Magnetic bubbles offer promise of data storage at a lower cost than is possible using semiconductor technologies. However, a memory using magnetic bubbles is most economically implemented in the form of long shift registers, rather than as a random access storage device. This plus a lower shift rate than is possible with semiconductors suggests relatively long average access times. This shortcoming is largely overcome by an organizational technique called dynamic ordering, which can reduce the average number of shifts needed to access data. A dynamically ordered magnetic bubble memory, when combined with one or more smaller semiconductor memories in a hierarchy, should provide both large capacity and good performance with reasonable economy.

Development of Water-soluble Systems for Use in Industrial Soldering Processes *by P. W. H. Schuessler, R. M. Poliak, and H. G. Peters, p. 592.* This communication discusses the engineering considerations involved in the design of low-polluting water-soluble systems for use in mechanized soldering processes. New formulations for water-soluble fluxes, lubricants, and solder masks are described and test data are presented.

Charge Transfer Complex Formation of Trinitrofluorenone with Polyvinylcarbazole and Ethylcarbazole *by G. Weiser and H. Seki, p. 598.* The molar absorption constants of the charge-transfer complexes of PVCz:TNF and of ethylcarbazole:TNF and the respective equilibrium constants for the formation of these complexes in a tetrahydrofuran solution have been determined by absorption measurements. Both materials exhibit two charge-transfer absorption bands. It is shown that these two bands correspond to two transitions of only one charge-transfer complex rather than to two complexes with different geometrical configurations of donor and acceptor molecules. For the PVCz:TNF complex the equilibrium constant is determined as $K = 0.5$ l/mole, which is much smaller than the value $K = 3.05$ l/mole found for the complex of ethylcarbazole and TNF.

Multiconductor Transmission-line Theory in the TEM Approximation *by W. T. Weeks, p. 604.* Starting with Maxwell's equations, the transmission line equations are derived for a system consisting of an arbitrary number of conductors. The derivation is rigorous for long lossless conductors embedded in a uniform perfect dielectric. The presentation is essentially tutorial, most of the results being well known, at least for two- and three-conductor systems. The novelty lies in the point of view adopted in obtaining a systematic generalization to the case of an arbitrary number of conductors. Explicit expressions are obtained for the electric and magnetic fields in the dielectric surrounding the conductors, and a rigorous formulation is given for the problem of calculating the coefficients of capacitance and inductance.

Solution of the Complete Symmetric Eigenproblem in a Virtual Memory Environment *by A. A. Dubrulle, p. 612.* Algorithms for the complete symmetric eigenproblem are studied from the viewpoint of performance in a virtual memory environment. The preferred algorithm is based on tridiagonalization and the implicit QR algorithms. Implementation factors that affect execution time are discussed.

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Steady State Mathematical Theory for the Insulated Gate Field Effect Transistor *by D. P. Kennedy and P. C. Murley, p. 2.* A two-dimensional mathematical analysis is presented of the mechanisms of operation for an insulated gate field effect transistor (IGFET). Included in this analysis are qualitative and quantitative comparisons between conventional one-dimensional theory and a rigorous two-dimensional computer solution for the IGFET. It is shown that many characteristics of device operation deduced from conventional theory cannot be verified on a two-dimensional basis because of mechanisms not presently taken into consideration by the theory. A modified one-dimensional mathematical theory is therefore proposed, to account for these mechanisms, that is in adequate agreement with a rigorous two-dimensional computer solution for this semiconductor problem.

Computer Interference Analysis *by W. Chang, p. 13.* This paper describes a single-server queuing model with Erlang input, which can be used for computer congestion analysis. The model is intended primarily for small computer systems in which the CPU is needed for input/output operations, which aggravates the interference problem.

The model provides such information as the queuing time distribution for channel requests and the CPU delay due to channel interference. The model is illustrated by numerical examples, and procedures for the analysis are shown.

Optimum Storage Allocation for a File in Steady State *by J. A. van der Pool, p. 27.* A file of fixed-length records in auxiliary storage using a key-to-address transformation to assign records to addresses is considered. The file is assumed to be in steady state, that is that the rates of additions to and of deletions from the file are equal.

The loading factors that minimize file maintenance costs in terms of storage space and additional accesses are computed for different bucket sizes and different operational conditions.

Transport Properties of the Semiconductor Superlattice *by P. J. Price, p. 39.* Precise calculations have been made, by Monte Carlo methods, of electron transport properties of the Esaki superlattice. The calculations were on a single-particle space-homogeneous basis, with a model of the superlattice which could be reasonably close to reality. Steady-state longitudinal drift-velocity/field characteristics were obtained, for four sets of parameter values; they exhibited the expected maximum followed by negative differential mobility. The accompanying variations of the longitudinal and transverse energy averages were also obtained, and the distribution functions for longitudinal wavevector and transverse energy were investigated. The frequency dependences of the differential mobilities (in-phase and out-of-phase components) were obtained in some representative cases; they exhibited a "Bloch resonance."

Age-specific, Deterministic Model of Predator-Prey Populations: Application to Isle Royale *by D. C. Gazis, E. W. Montroll, and J. E. Ryniker, p. 47.* A deterministic model is proposed for the description of predator-prey systems in which the prey has an age-specific vulnerability to predation. The model is developed on the basis of observations of the moose and wolf populations of Isle Royale, Michigan. The moose are divided into three groups, the very young, the adults, and the very old or sick. The three groups have different vulnerability to predation by a single population of wolves. The model incorporates a saturation effect for the moose population and a satiation effect for the wolf population. It appears to reproduce quite well the almost monotonic trend toward equilibrium observed since the arrival of wolves on the island.

Digital-to-analog Converter having Common-mode Isolation and Differential Output *by G. A. Hellwarth and S. Boinodiris, p. 54.* A digital-to-analog converter (DAC) is described that has transformer-coupled isolation for both power and data inputs and provides a true differential output. The DAC provides a 10-bit, 10.23-V unipolar output of either polarity, depending on which of the two output lines is used as the load reference potential. The common-mode potential may be as large as 250 V, and below 120 Hz the common-mode rejection typically exceeds 100 dB. The isolated, balanced circuit eliminates environmental noise problems and permits long cabling lengths without loss of dc accuracy. The DAC is an analog output feature available on the IBM System/7, a small computer designed for data acquisition and real-time automation applications.

An AlN Switchable Memory Resistor Capable of a 20-MHz Cycling Rate and 500-picosecond Switching Time *by R. F. Rutz, E. P. Harris, and J. J. Cuomo, p. 61.* We report here the operational characteristics of multistable resistance switching devices made from thin sputtered layers of AlN. These devices exhibit switching between high and low resistance states when proper electrical signals are applied. Repetitive switching at 20-MHz rates has been achieved, and switching times in the best units have been observed to be less than 500 picoseconds. These are believed to be the first active electronic switching devices to be reported utilizing AlN.

Amorphous Metallic Films for Bubble Domain Applications *by P. Chaudhari, J. J. Cuomo, and R. J. Gambino, p. 66.* We have found that sputtered amorphous films of Gd-Co and Gd-Fe have perpendicular magnetic anisotropy. The demagnetized domain configuration consists of stripe domains, and bubble domains were nucleated in an applied field. By controlling the sputtering conditions, films with a wide variety of magnetic properties were obtained.

APLGOL, an Experimental Structured Programming Language *by R. A. Kelley, p. 69.* An experimental programming language called APLGOL adds structured

programming facilities to the existing framework of APL. The conventional semantics of APL is unaltered and only minor changes are incorporated in the syntax. The advantages of the proposed interstatement structuring and control are outlined.

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Empirically Derived Micromodels for Sequences of Page Exceptions *by P. A. W. Lewis and G. S. Shedler, p. 86.* Based on a statistical analysis of actual computer program address traces, some results are presented of a study aimed at deriving empirically valid stochastic models for program reference patterns in a computer system operating under demand paging. For the address traces examined, a semi-Markov model for the (univariate) point process of page exceptions is formulated and found to be an adequate characterization of the data.

Bounds for Weight Balanced Trees *by J. Rissanen, p. 101.* It has been shown that the cost W of a weight balanced binary tree satisfies the inequalities, $H \leq W \leq H + 3$, where H is the entropy of the set of the leaves. For a class of "smooth" distributions the inequalities, $H \leq W \leq H + 2$, are derived.

These results imply that for sets with large entropy the search times provided by such trees cannot be substantially shortened when binary decisions are being used.

Optimum Storage Allocation for a File with Open Addressing *by J. A. van der Pool, p. 106.* File organizations utilizing key-to-address transformation and open addressing are studied. A simulation method and a Markov model, which were used for evaluation, are presented. The cost of retrieval as a function of storage space and accesses is also formulated. The minimum of the combined costs for different operational conditions is determined.

Quasimaximum Likelihood Estimators for Two-parameter Gamma Distributions *by E. W. Stacy, p. 115.* The Gamma probability distribution is defined by the density function $[\beta^{\alpha}\Gamma(\alpha)]^{-1} \exp(-x/\beta)$. This paper presents new estimators for the parameters α^{-1} and β. Required calculations are simple, primarily involving the inner product of certain elementary statistics and their logarithms. Both of the new estimators are shown to be unbiased. The variance formulas for each and their covariance formula are derived—counterparts of these for the method of moments (MM) and the method of maximum likelihood (ML) not being known except in the asymptotic form. Curve-fitting results from samples of size 50 are provided. They support the proposition that the new quasimaximum likelihood estimators (QML) are at least as effective as MM and ML estimators. Illustrative estimation based on samples of size 5 also is presented for comparison; the results highlight relative smaller variances for the ML estimators. The same Monte Carlo results signal a possibility that significant negative bias occurs with both the MM and ML techniques if small samples are used.

Theory of MNOS Memory Device Behavior *by A. V. Ferris-Prabhu, p. 125.* This paper extends the direct-tunneling theory of MNOS memory device behavior to account for traps that are distributed both spatially and energetically. It shows that the Pulver and Dorda model is a special case of the Ross and Wallmark model, which is itself a restricted version of the more general theory proposed here.

A general equation for the total charge transfer is derived, for monoenergetic and for energetically uniform trap distributions, for high fields as well as low fields. The theory predicts the time dependence of the total charge transfer to be initially linear, then roughly logarithmic, and finally to reach saturation. There is no essential difference in the results whether the trap distribution is monoenergetic or energetically uniform. The operational dependence on characteristic parameters is investigated and found to be greatest for changes in the extent of spatial distribution of traps. The switching time varies inversely with trap density and tunnelling probability, and exponentially with the oxide thickness.

Axioms and Theorems for a Theory of Arrays *by T. More, Jr., p. 135.* Array theory combines APL with set theory, transfinite arithmetic, and operationally transformed functions to produce an axiomatic theory in which the theorems hold for all arrays having any finite number of axes of arbitrary countable ordinal lengths. The items of an array are again arrays. The treatment of ordinal numbers and letters is similar to Quine's treatment of individuals in set theory. The theory is developed first as a theory of lists.

This paper relates the theory to the eight axioms of Zermelo-Fraenkel set theory, describes the structure of arrays, interprets empty arrays in terms of vector spaces, presents a system of axioms for certain properties of operations related to the APL function of reshaping, deduces a few hundred theorems and corollaries, develops an algebra for determining the behavior of operations applied to empty arrays, begins the axiomatic development of a replacement operator, and provides an informal account of unions. Cartesian products, Cartesian arrays, and outer, positional, separation, and reduction transforms.

Automatic Equalizers having Minimum Adjustment Time *by M. Karnaugh, p. 176.* Two new types of automatic equalizers for telephone lines are discussed. The modular configurations shown are designed for minimum adjustment time and are ready to receive data as soon as the response of the unequalized line has been measured. Two forms of such equalizers are compared with respect to upper bounds on the residual distortion.

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Comparison of Two Methods of Modeling Stationary EEG Signals *by T. Bohlin, p. 194.* This paper compares the performances—when applied to stationary EEG signals—of two methods of modeling stochastic time-series; viz, a maximum-likelihood search method for a mixed autoregressive and moving-average time-series, and the well-known method of least-squares identification of a prefiltered autoregressive series. Computing effort per step is derived for different-order search strategies, expressed in the number of a set of basic operations and also in equivalent number of likelihood function evaluations. Power spectra and total computing effort are evaluated and compared for four representative EEG samples. It appears that the least-squares method is generally superior because iteration is not needed, and in spite of the fact that higher orders are needed instead.

X-ray Image Subtraction by Digital Means *by C. K. Chow, S. K. Hilal, M.D., and K. E. Niebuhr, p. 206.* A conventional method of removing unwanted background information from radiographic images is to use photographic techniques. An alternative approach is the digital processing of x-ray difference images. This approach offers the advantage over photographic methods in that it permits the performance of nonlinear operations, such as compensation for film characteristics, thus offering greater flexibility in the presentation of x-ray images and greater reliability in their interpretation. This paper describes the features and implementation of a new digital approach and presents experimental results obtained from processing two sets of angiograms.

Action Potential of the Motorneuron *by F. A. Dodge, Jr. and J. W. Cooley, p. 219.* The excitability of various regions of the spinal motorneuron can be specified by solving the partial differential equation of a nerve fiber whose diameter and membrane properties vary with distance. For our model geometrical factors for the myelinated axon, initial segment and cell body were derived from anatomical measurements, the dendritic tree was represented by its equivalent cylinder, and the current-voltage relations of the membrane were described by a modification of the Hodgkin-Huxley model that fits voltage-clamp data from the motorneuron. In order to compute spike waveforms that match experimental observations, 1) the dendritic membrane must be inexcitable, 2) the voltage threshold of the initial segment of the axon must be ten millivolts lower than that of the cell body, and 3) the density of sodium conductance in the initial segment must be ten times greater than in a typical unmyelinated axon.

Identifying and Understanding Patterns and Processes in Human Shock and Trauma *by R. M. Goldwyn, E. J. Farrell, H. P. Friedman, M. Miller, and J. H. Siegel, M.D., p. 230.* The aim of this paper is to provide an overview of an on-going collaborative effort of research physicians, computer scientists, and statisticians to develop a quantitative way of understanding the clinical course of a critically ill and injured patient. The method is based on a multivariable analysis of time series of individual physiologic measurements. The ultimate goal is to reduce a large body of complex physiologic data to an information base that is relatively small and simple so that abnormal patterns may be exposed in a manner that can be directly interpreted and utilized at the bedside by the attending clinician to improve patient care. In this paper we describe some contributions made toward reaching this goal.

Performance of Very High Density Charge Coupled Devices *by N. A. Patrin, p. 241.* The results of an experimental study of the performance of very high density 8, 128, and 256 bit CCD shift register structures are presented. The primary topics discussed include transfer efficiency, frequency response, impact of "fat zero" operation, and observed temperature dependency.

Theory and Computer-aided Analysis of Lossless Transmission Lines *by C. W. Ho, p. 249.* A theoretical analysis of coupled and uncoupled lossless transmission lines is presented. A new method for deriving the conductance matrix **G** is described. Networks containing such lines have been simulated in the time domain and some results obtained from simulation of two example networks are given.

Refractive Index Dispersion in Semiconductor-related Thin Films *by A. J. Warnecke and P. J. LoPresti, p. 256.* A technique is described for determining refractive index dispersion throughout the uv-visible spectrum in semiconductor-related transparent thin films. The dispersion constants that have been measured can be used in the design of optical systems and in photolithography. Measurements were made with the LASER-VAMFO interferometer. Calculations and analyses are also described which show the accuracy and repeatability of the technique. Data were taken for 28 different thin-film materials, and representative refractive index dispersion curves are shown for some of them. The dispersion constants for each material evaluated are also presented.

Experimental Study of Deadline Scheduling for Interactive Systems *by D. D. Chamberlin, H. P. Schlaeppi, and I. Wladawsky, p. 263.* This paper outlines a resource allocation strategy called deadline scheduling, which is intended for use in interactive systems. Experiments are reported in which simplified versions of deadline scheduling and two time slicing strategies are modeled and compared under identical conditions. Results suggest that deadline scheduling, primarily by reducing paging overhead, provides faster response and supports more interactive users concurrently than do the two time slicing methods.

Asymptotic Expansion for Small Magnetic Fields of Acoustoelectric Attenuation in Nondegenerate Semiconductors *by J. S. Lew, p. 270.* The semiclassical

analysis of acoustoelectric effects involves an infinite sum

$$S(c,x) = ic \exp(-x) \sum_{n=-\infty}^{+\infty} (n+ic)^{-1} I_n(x),$$

in which both arguments c and x depend on the magnetic field B. Recently Lebwohl, Carlson, and Mosekilde have found an integral representation for this sum, through which now we identify $S(c,x)$ as a generalized hypergeometric function. Moreover we derive an asymptotic series for $S(c,x)$ in the limit of small B, whose coefficients, in a parameter z, involve the iterated integrals of the complementary error function.

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Numerical Calculation of Self-Focusing and Trapping of a Short Light Pulse in Kerr Liquids *by F. Shimizu, p. 286.* Self-focusing and trapping of an intense, short light pulse is discussed on the basis of a parabolic scalar wave equation which includes a quadratic nonlinear refractive index. When the finite relaxation time of the nonlinear index is taken into account, the propagation properties of the transient solution differ considerably from those of the time-independent solution. Based mainly on the results of our numerical calculations, we show that contraction of the self-focusing pulse stops at a finite radius and that part of the pulse remains trapped beyond this focal point. The limiting radius decreases rather rapidly with increasing input power as well as with pulse width. However, if we assume a cutoff radius, the resulting filament accounts for experiments performed with multimode lasers. Effects of stimulated Raman scattering and dispersion are also discussed.

Effects of Dispersion on Steady State Electromagnetic Shock Profiles *by S.-T. Peng and R. Landauer, p. 299.* In nonlinear electromagnetic media the various portions of a wave can travel with different velocities, which can result in the formation of electromagnetic shock waves. The structure of such a steady state shock is determined by an equilibrium between the velocity differences that tend to sharpen the shock and the sources of dispersion that cause a broadening of the shock. Several nonlinear transmission line models are examined for the nature and existence of a single-valued steady state shock. In all cases a nonlinear shunt capacitance is assumed. If the dispersion arises from the relaxation behavior caused by a resistance in series with the nonlinear capacitance, a steady shock always exists, its width decreasing as the extent of the nonlinearity generated by the shock increases. If the series resistance is itself shunted by another capacitance, the relaxation process is not manifested at very high frequencies. This system yields a critical condition for the existence of a continuous single-valued steady state wave profile. If the line has too little dispersion, the steady state profile is multivalued and therefore physically unrealizable.

These dispersion requirements are equivalent to the condition that the velocity of small, high frequency signals ahead of the shock must be greater than the velocity of the shock itself. It is believed that this condition is a broadly applicable criterion for the existence of a stable, single-valued, steady state wave profile. While this hypothesis is not proved analytically, it is supported here by plausibility arguments and by analysis of another system in which the dispersion is included in the linear series inductance rather than in the nonlinear shunt capacitance.

On a Nonlinear Diffusion Equation Describing Population Growth *by J. Canosa, p. 307.* A nonlinear eigenvalue problem is solved analytically to obtain the shock-like traveling waves of Fisher's nonlinear diffusion equation, with which he described the wave of advance of advantageous genes. A phase-plane analysis of the wave profiles shows that the propagation speed of the waves is linearly proportional to their thickness. The analytic solution is asymptotically accurate in the limit of infinitely large characteristic speeds. However, as they have a minimum threshold value which is not zero, the asymptotic solution turns out to be highly accurate for all propagation speeds. The wave profiles of Fisher's equation are shown to be identical to the steady state solutions of the Korteweg-de Vries-Burgers equation that are obtained when dissipative effects are dominant over dispersive effects.

Linearization of Cauchy's Problem for Quadratic Semilinear Partial Differential Equations *by P. D. Gerber, p. 314.* The technique of linearization is applied to quadratic semilinear systems of n first-order partial differential equations. By introducing a related linear algebra A, we combine analytic and algebraic arguments to obtain a class of linearizable systems. We relate the coefficients of such systems to the center of A and show that, for hyperbolic systems, the ideals of A decouple the system into disjoint subsystems each having its own single wave number.

The Design of APL *by A. D. Falkoff and K. E. Iverson, p. 324.* This paper discusses the development of APL, emphasizing and illustrating the principles underlying its design. The principle of simplicity appears most strongly in the minimization of rules governing the behavior of APL objects, while the principle of practicality is served by the design process itself, which relies heavily on experimentation. The paper gives the rationale for many specific design choices, including the necessary adjuncts for system management.

General Arrays, Operators and Functions *by Z. Ghandour and J. Mezei, p. 335.* This paper discusses "general arrays," i.e., arrays in which the items are either scalars or other arrays. Functions are defined to construct, select from, restructure, and in general manipulate such arrays. Operators are presented as functions whose arguments or values are other functions that can be other than scalar functions. The exposition is shortened and simplified by presenting the material throughout in terms of APL.

System Formulation and APL Shared Variables *by R. H. Lathwell, p. 353.* The problem of providing communication

with APL programs was approached by formulating systems as collections of autonomous processors communicating on interfaces consisting of shared variables. This paper discusses the formulation of a theoretical APL system and cites experience with a prototype APL shared variable system which both uses and provides shared variable interfaces.

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Decomposition of a Data Base and the Theory of Boolean Switching Functions *by C. Delobel and R. G. Casey, p. 374.* The notion of a functional relation among the attributes of a data set can be fruitfully applied in the structuring of an information system. These relations are meaningful both to the user of the system in his semantic understanding of the data, and to the designer in implementing the system. An important equivalence between operations with functional relations and operations with analogous Boolean functions is demonstrated in this paper. The equivalence is computationally helpful in exploring the properties of a given set of functional relations, as well as in the task of partitioning a data set into subfiles for efficient implementation.

Characterization of Program Paging in a Time-sharing Environment *by Y. Bard, p. 387.* This paper describes a method for predicting the paging behavior of a program in a virtual memory multiprogramming environment. The effect of overall system activity on the program is summarized in one parameter, the page survival index. The model correlates well with observations taken on programs running under CP-67. The model can be used for paging load prediction, simulator input verification, and evaluation of program rearrangement and sharing.

Response Time Characterization of an Information Retrieval System *by H. F. Silverman and P. C. Yue, p. 394.* A methodology for computer performance evaluation based on the statistical characterization of response time is described. The results of its application to an information retrieval system are presented. The first part of the paper gives a general discussion of measurement techniques, data reduction procedures and the structure of the system being examined. A set of "system environment" parameters and a set of "job" parameters are then defined and appraised in terms of actual measurements collected over two different weekly periods. Various ways of using the statistical characterization for improving performance are then considered.

An Analysis of Page Allocation Strategies for Multiprogramming Systems with Virtual Memory *by D. D. Chamberlin, S. H. Fuller, and L. Y. Liu, p. 404.* In a multiprogramming, virtual-memory computing system, many processes compete for the main storage page frames and CPU's of the real system. It is customary to define a subset of these processes called the "multiprogramming set" (MPS), and to allocate resources only to those processes currently in the MPS. Each process remains in the MPS for a limited time and is then demoted. The system paging manager controls the size of the MPS; it allocates the available page frames among the processes in the MPS and fetches appropriate pages into the page frames.

A model is described that assumes the most critical resources of the system to be page frames and the paging channel (i.e., there is no significant CPU contention). The model makes certain assumptions about the page fault rate of processes as a function of page frames allocated, and about the page fetch time as a function of mean load on the paging channel. The model also incorporates a definition of the value of a given page allocation in terms of system throughput.

The model is used to study various strategies for choosing an MPS and allocating page frames among processes. For simple cases, the model yields an exact optimal strategy. A heuristic strategy is proposed for dealing with more complex cases, and is shown by the model to be reasonably near optimal. The heuristic strategy monitors the page fault rate of each process and chooses an allocation such that each process can be executed at a reasonable rate, while ensuring that the paging channel is neither overloaded nor underloaded.

A Decision-feedback Receiver for Channels with Strong Intersymbol Interference *by H. Kobayashi and D. T. Tang, p. 413.* This paper deals with the problem of equalizing channels containing strong intersymbol interference. Typical of such channels are those of digital magnetic recording systems and data communication systems with partial-response signaling. First we discuss reasons that a conventional receiver with a linear equalizer cannot efficiently compensate for distortion in such channels. We then present a new receiver configuration in which the equalizer and quantizer are embedded in an inverse filter circuit that eliminates major intersymbol interference components. This configuration allows us to use a simple iteration algorithm to adaptively adjust the equalizer. Application of the scheme to digital magnetic recording data is discussed as an illustrative example.

Lower Bounds for the Partitioning of Graphs *by W. E. Donath and A. J. Hoffman, p. 420.* Let a k-partition of a graph be a division of the vertices into k disjoint subsets containing $m_1 \geq m_2, \ldots, \geq m_k$ vertices. Let E_c be the number of edges whose two vertices belong to different subsets. Let $\lambda_1 \geq \lambda_2, \ldots, \geq \lambda_k$ be the k largest eigenvalues of a matrix, which is the sum of the adjacency matrix of the graph plus any diagonal matrix U such that the sum of all the elements of the sum matrix is zero. Then

$$E_c \geq \tfrac{1}{2} \sum_{r=1}^{k} - m_r \lambda_r.$$

A theorem is given that shows the effect of the maximum degree of any node being limited, and it is also shown that the right-hand side is a concave function of U. Computational

studies are made of the ratio of upper bound to lower bound for the two-partition of a number of random graphs having up to 100 nodes.

Dislocations in Gadolinium Gallium Garnet ($Gd_3Ga_5O_{12}$): III. Nature of Prismatic Loops and Helical Dislocations *by J. W. Matthews, E. Klokholm, and T. S. Plaskett, p. 426.* Thin garnet films suitable for magnetic bubble devices can be made by depositing the film material onto nonmagnetic garnets such as $Gd_3Ga_5O_{12}$ (GGG). The performance of these devices is influenced by the dislocation content of the films. This, in turn, depends on the dislocation content of the substrate. Dislocations in the substrate can be detected by means of the birefringence they induce, or from the etch pits formed where they meet the sample surface. Most of the dislocations revealed by these techniques have been climb loops around inclusions and helical dislocations. This paper describes an optical method for determining the sign of the stresses at inclusions and nature of loops and helical dislocations. The method has shown that iridium inclusions are compressed by the matrix and that the loops and helices in GGG are extrinsic; they grow either by the emission of vacancies or the absorption of interstitial atoms.

Design and Characteristics of n-Channel Insulated-gate Field-effect Transistors *by D. L. Critchlow, R. H. Dennard, and S. E. Schuster, p. 430.* An *n*-channel insulated-gate field-effect transistor technology established at IBM Research has served as the basis for further development leading to FET memory. Designs and characteristics of experimental devices of 500 and 1000 Å gate insulator thicknesses are presented, with particular attention to the effects of source-drain spacing.

Theory and Operation of Space-charge-limited Transistors with Transverse Injection *by S. Magdo, p. 443.* The development of a new device, called the space-charge-limited (SCL) transistor with transverse injection is reported in this paper. A theoretical model for space-charge-limited transistors, both npn and pnp, on high-resistivity silicon substrates is described and a quantitative analysis is given. Experimental results for SCL transistors are presented to support the model's validity. According to the model, current in SCL transistors is controlled by the base of a parallel-connected lateral transistor in two ways. First, the base of the parallel transistor controls the potential step in the high resistivity base of the SCL transistor. Second, the base of the parallel transistor injects carriers in the direction transverse to the SCL current flow. These carriers are of types opposite to those that carry the current flow in the SCL transistor and thus partly neutralize the space-charge in the current flow. The carriers propagate, predominantly by drift, across the high-resistivity base region of the SCL transistor. The resulting base transit time is about two orders of magnitude faster than that of a bipolar transistor with equal base width. No charge storage takes place in saturation. These features and the very low device capacitances make the SCL transistor attractive for low-power, fast-switching applications. Current gains as high as 70,000 are obtained at low current levels. The current gain decreases at higher current levels because the parallel lateral transistor turns on. It is also demonstrated that complementary pairs of SCL transistors can be fabricated with three masking steps, including metalization.

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Design and Operation of ETA, an Automated Ellipsometer *by P. S. Hauge and F. H. Dill, p. 472.* The design and operational features are described for a computer-assisted ellipsometer (called ETA for Ellipsometric Thickness Analyzer), developed to provide reliable, real-time measurement of field-effect transistor gate insulator thickness in a manufacturing environment. ETA illuminates the sample with light of fixed polarization and uses a rotating analyzer to measure the polarization of the reflected light. Sample alignment is done automatically by ETA, so that usually no operator adjustments are required. Fourier analysis of the light transmitted by the analyzer is used to reduce noise and enhance measurement precision.

In its normal mode of operation (incident light linearly polarized at 45°), ETA can measure single and double-layer films of SiO_2 and Si_3N_4 in the thickness range of 300 to 800 Å with precision comparable to that of conventional ellipsometers. Other modes of operation, which make use of a fixed-position compensator in the incident light path, allow precise measurement of thin films (0 to 300 Å) and permit use of ETA as a general-purpose ellipsometer. The typical time interval required for wafer alignment, data acquisition, analysis and recorded output of film thickness is about five seconds, and the measurement reproducibility is typically about 1 Å.

Rapid, Precise, Computer-controlled Measurement of *X-Y* Coordinates *by M. Kallmeyer, K. Kosanke, F. Schedewie, B. Solf, and D. Wagner, p. 490.* An experimental *x-y* measurement system is described that was designed for the high-speed, high-precision measurements required in integrated circuit manufacturing and for optical measurement applications in which a sufficiently large data base is required for statistical process analysis. The technology for this experimental system differs considerably from that of conventional optical measuring systems in current use and utilizes a computer for data acquisition, manipulation and evaluation. The system, utilizing the edge detection principle, presently operates at a measuring speed of 2.5 cm/s. An analysis gives both the short-term and the long-term precision of the system. The standard deviation for the short-term precision is 0.038 μm.

Interactive Use of a Time-shared Process Control Computer in Electrophotographic Sensitometry *by B. H. Schechtman, S. S. So, and E. W. Luttman, p. 500.* The usefulness of electrophotographic exposure sensitometry as a

means of characterizing and evaluating new photoconductor materials has been extended by coupling the experiment to an on-line computer. This automated system provides several new functional capabilities not realistically attainable in manual operation and drastically reduces the time lag in the exchange of information between research workers who prepare materials and those who evaluate the materials. These various improvements have been achieved by extensive use of interactive graphic techniques and a user-oriented data-base organization.

Dimensional Measurement and Defect Detection Using Spatial Filtering *by A. L. Flamholz and H. A. Froot, p. 509.* A new method is described that utilizes coherent bandpass spatial filtering and subsequent superposition to form filtered images in which small differences in size and geometry of the original object are readily detected. The theoretical basis is discussed and experiments described in which signal ratios of about 10:1 are obtained for a diameter change of 2.5 percent of a clear circular disc. The method is used to process in parallel a 57-mm evaporation mask containing 12,000 holes, each being 0.1 mm in diameter. The size of each hole is accurately gauged and small imperfections are indicated in the filtered image.

Optical Techniques for Measurement of Chamber Spacing *by J. C. Chastang, p. 519.* Two optical methods were investigated for accurately measuring the gap, or chamber spacing, that separates two closely spaced transparent plates. The first method uses a special microscope in which the main feature is a unit-magnification catadioptric system that gives an aberration-free image of the chamber outside the plates, where it is accessible to a high-power objective. The second method is based upon the light section principle, whereby the image of a slit is projected onto the boundaries of the chamber and is thus doubled. The reflected images are observed with a microscope and the degree of separation, which is proportional to the chamber spacing, is measured. Accuracy better than 2 μm is obtained for the two techniques. The choice of the appropriate method depends on the surface quality of the chamber boundaries.

Logical Reversibility of Computation *by C. H. Bennett, p. 525.* The usual general-purpose computing automaton (e.g., a Turing machine) is logically irreversible—its transition function lacks a single-valued inverse. Here it is shown that such machines may be made logically reversible at every step, while retaining their simplicity and their ability to do general computations. This result is of great physical interest because it makes plausible the existence of thermodynamically reversible computers which could perform useful computations at useful speed while dissipating considerably less than kT of energy per logical step. In the first stage of its computation the logically reversible automaton parallels the corresponding irreversible automaton, except that it saves all intermediate results, thereby avoiding the irreversible operation of erasure. The second stage consists of printing out the desired output. The third stage then reversibly disposes of all the undesired intermediate results by retracing the steps of the first stage in backward order (a process which is only possible because the first stage has been carried out reversibly), thereby restoring the machine (except for the now-written output tape) to its original condition. The final machine configuration thus contains the desired output and a reconstructed copy of the input, but no other undesired data. The foregoing results are demonstrated explicitly using a type of three-tape Turing machine. The biosynthesis of messenger RNA is discussed as a physical example of reversible computation.

Approximating Pre-emptive Priority Dispatching in a Multiprogramming Model *by H. A. Anderson, Jr., p. 533.* The formulation of the closed queuing network model of a multiprogramming computer system is generalized to allow each task to have its own set of facility service rates and I/O device selection probability distribution. In the model, processor sharing is assumed for different types of customers. It is shown through a series of investigations that the model reasonably approximates preemptive priority dispatching.

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On-line Measurement of Paging Behavior by the Multivalued MIN Algorithm *by L. A. Belady and F. P. Palermo, p. 2.* An algorithm is presented that extracts the sequence of minimum memory capacities (MMCs) from the sequence of page references generated by a program as it is executed in a demand paging environment. The new algorithm combines the advantages of existing approaches in that the MMCs are produced in a single pass, as is the output of the MIN algorithm for a single memory size, and the MMC sequence is identical to the optimum stack distances provided by the OPT algorithm, which requires two passes.

A hardware implementation is outlined as an extension to existing page management mechanisms. The resulting device could be used to produce continuously the MMC information, while the (paging) machine executes the program at essentially full speed. The paper also discusses the possible impact of the algorithm on the study of program behavior and on the development of space sharing (paging) algorithms. Finally, a proof is provided that the algorithm in fact produces an output identical to that of OPT.

Register Assignment Algorithm for Generation of Highly Optimized Object Code *by J. C. Beatty, p. 20.* A register assignment algorithm is described that, in contrast to traditional methods, permits a high level of optimization at both local and global levels. This involves splitting local register optimization into two phases, with global assignment intervening. Because novel techniques are used in the global assignment procedure, it is described in detail. Experimental results with a prototype implementation are presented in which object code improvements on the order of 25 percent over a production optimizing compiler were obtained. No attempt was made to assess manpower costs of a final implementation nor to weight them against expected improvements in generated code.

Water Vapor as an Oxidant in BBr_3 Open-tube Silicon Diffusion Systems *by R. F. Lever and H. M. Demsky, p. 40.* The use of water vapor as an oxidant in place of oxygen enables a wide range of surface concentrations to be obtained in a single-step process. The concentration of boron at the silicon surface is found not to be constant throughout the diffusion process because, at the temperature used, the oxide growth is not parabolic.

Potential Distribution of an Inhomogeneously Doped MIS Array *by W.-H. Chang and H.-S. Lee, p. 47.* A numerical method is used to obtain the potential distribution of a two-dimensional, inhomogeneously doped MIS array under pulse voltage operation. The effects of interface charge and of impurity doping and its locations on the surface potential profile are presented. The technique is useful for designing an appropriate surface potential profile for ion-implanted charge-coupled devices.

Numerical Calculation of Normal Modes for Underwater Sound Propagation *by H. M. Beisner, p. 53.* Hartree's method for calculation of atomic wave functions is applied to the Schroedinger-like normal mode equation for underwater sound propagation. Rapid convergence was obtained for the twelve normal modes at five Hertz with a typical velocity profile. The normal modes are given, along with an example of the pressure field, and a means for numerical calculation of the near field modes is suggested.

Stability Criterion for Recursive Filters *by P. Pistor, p. 59.* A new criterion is derived that relates the stability of two-dimensional recursive filters to the properties of its cepstrum. It provides a procedure for the decomposition of unstable recursive filters having nonzero, nonimaginary frequency response into stable recursive filters. The optimal solution of the decomposition problem is discussed, including numerical implementation and nonrecursive solutions. Several numerical examples show the potentialities and limitations of the rules for decomposition and for truncation of the operators.

Economic Order and Surplus Quantities Model *by M. N. El Agizy, p. 72.* A standard mathematical model for inventory management is known as the Economic Order Quantity (EOQ) model. In this communication the EOQ model is extended to include the possibility of determining how much, if any, excess stock should be sold at the beginning of a decision period. The new model is of practical importance for situations in which a formal inventory management system is to be instituted while substantial inventories exist or when changes in demand, ordering costs, or carrying and interest charges require recomputation of the economic order quantity.

Preparation of Large-area Electron-transparent Samples from Silicon Devices *by G. Das and N. A. O'Neil, p. 76.* A technique using a pulsating chemical jet has been developed for thinning and polishing large areas (750 to 1000 μm in diameter) of silicon devices. The thickness can be reduced to a few micrometers. This technique has been used to prepare bipolar and FET samples for transmission electron microscopy. Physical characterization of more than twenty devices can be achieved by one sample preparation.

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Interface Imaging by Scanning Internal Photoemission *by T. H. DiStefano and J. M. Viggiano, p. 94.* A scanning internal photoemission (SIP) technique is used to obtain a high resolution map or image of the potential energy barrier at an insulator interface. The image is produced by displaying the internal photocurrent produced by a monochromatic beam of light scanned across the sample. A special technique was developed for focusing the light to a spot less than one micrometer in diameter. Photoemission images of a Si-SiO_2 interface "stained" with a fractional monolayer of sodium are

presented along with photoemission and reflectively images of a Nb_2O_5-Bi interface. These SIP images show inhomogeneities related to structural variations, impurities, and defects at the interface that previously were inaccessible to observation.

Calculations of Stable Domain Radii Produced by Thermomagnetic Writing *by B. G. Huth, p. 100.* Calculations are performed to determine the stable radius of a cylindrically symmetric domain nucleated in magneto-optical films during thermomagnetic writing with a laser beam. A critical bound on domain size is calculated which determines whether or not a domain of given radius, once nucleated, will be stable. The analysis shows that for a ferromagnetic material such as MnAlGe, the domain dimensions can grow beyond the local region of material that is heated above the Curie temperature. For ferrimagnetic thin films having a compensation point T_{comp}, stability depends on the difference between ambient and compensation temperatures, $\Delta T = T_a - T_{comp.}$ With $\Delta T \approx 0$, wall energy dominates and the critical radius can be calculated from $R_c = \sigma/(2MH_c)$.

Accuracy of the Diffusion Approximation for Some Queuing Systems *by M. Reiser and H. Kobayashi, p. 110.* This paper presents the results of a rather extensive study of the accuracy of the diffusion approximation technique as applied to queuing models. The motive for using the diffusion process approximation here is to develop realistic analytical models of computing systems by considering service time distributions of a general form. We first review the theory of the diffusion approximation for a single server and then develop a new and simplified treatment of a queuing network system. The accuracy of this approximation method is then considered for a wide class of distributional forms of service and interarrival times and for various queuing models. The approximate solutions and exact (or simulation) solutions are compared numerically in terms of the means and variances of queue sizes, server utilizations, the asymptotic decrements of the distributions, and the queue size distributions themselves.

The accuracy of the diffusion approximation is found to be quite adequate in most cases and is considerably higher than that obtained by an exponential server model that is prevalent in computer system modeling.

Investigation into Scheduling for an Interactive Computing System *by H. A. Anderson, Jr. and R. G. Sargent, p. 125.* This paper describes a statistical evaluation of the performance of the swap scheduling algorithm of an interactive computer system and an investigation into foreground-background scheduling to improve system performance. Input traffic, computer service time demands, and system performance were statistically analyzed. Based on the results of these analyses performance enhancements for the system were determined and then evaluated through use of a validated simulation model.

Parallel Solution of Recurrence Problems *by P. M. Kogge, p. 138.* An mth-order recurrence problem is defined as the computation of the sequence $x_1, ..., x_N$, where $x_i = f(\mathbf{a}_i, x_{i-1}, ..., x_{i-m})$ and $\mathbf{a}_i$ is some vector of parameters. This paper investigates general algorithms for solving such problems on highly parallel computers. We show that if the recurrence function f has associated with it two other functions that satisfy certain composition properties, then we can construct elegant and efficient parallel algorithms that can compute all N elements of the series in time proportional to $\lceil \log_2 N \rceil$. The class of problems having this property includes linear recurrences of all orders—both homogeneous and inhomogeneous, recurrences involving matrix or binary quantities, and various nonlinear problems involving operations such as computation with matrix inverses, exponentiation, and modulo division.

Self-directional Microwave Communication System *by E. L. Gruenberg, H. P. Raabe, and C. T. Tsitsera, p. 149.* This paper describes a communication system in which sending and receiving terminals automatically generate beams focused upon each other, which arise solely from ambient noise. The terminals are amplifying retrodirective arrays of antenna elements. Analysis and experiment are used to prove and verify the system concept. Some engineering considerations pertinent to system operation under various conditions are also analyzed and discussed.

Image Data Compression by Predictive Coding I: Prediction Algorithms *by H. Kobayashi and L. R. Bahl, p. 164.* This paper deals with predictive coding techniques for efficient transmission or storage of two-level (black and white) digital images. Part I discusses algorithms for prediction. A predictor transforms the two-dimensional dependence in the original data into a form which can be handled by coding techniques for one-dimensional data. The implementation and performance of a fixed predictor, an adaptive predictor with finite memory, and an adaptive linear predictor are discussed. Results of experiments performed on various types of scanned images are also presented. Part II deals with techniques for encoding the prediction error pattern to achieve compression of data.

Image Data Compression by Predictive Coding II: Encoding Algorithms *by L. R. Bahl and H. Kobayashi, p. 172.* This paper deals with predictive coding techniques for efficient transmission or storage of two-level (black and white) digital images. Part I discussed algorithms for prediction. Part II deals with coding techniques for encoding the prediction error pattern. First, we survey some schemes for encoding if the error pattern is assumed to be memoryless. Than a method is developed for encoding certain run-length distributions. Finally, some experimental results for sample documents are presented.

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On Optimization of Storage Hierarchies *by C. K. Chow, p. 194.* A simple model of the storage hierarchies is formulated with the assumptions that the effect of the storage management strategy is characterized by the hit ratio function. The hit ratio function and the device technology-cost function are assumed to be representable by power functions (or piece-wise power functions). The optimization of this model is a geometric programming problem. An explicit formula for the minimum hierarchy access time is derived; the capacity and technology of each storage level are determined. The optimal number of storage levels in a hierarchy is shown to be directly proportional to the logarithm of the systems capacity with the constant of proportionality dependent upon the technology and hit ratio characteristics. The optimal cost ratio of adjacent storage levels is constant, as are the ratios of the device access times and storage capacities of the adjacent levels. An illustration of the effect of overhead cost and level-dependent cost, such as the cost per "box" and cost for managing memory faults is given and several generalizations are presented.

Loss of Point-to-Point Traffic in Three-Stage Circuit Switches *by M. Karnaugh, p. 204.* A theoretical study is made of simple analytical models for the point-to-point loss of telecommunication traffic caused by blocking in three-stage circuit switches. Two new models are compared with Jacobaeus' frequently used model and with some simulation results to determine regions of acceptable accuracy. The effects of random hunting and sequential hunting for routes are compared by simulation.

The results apply to space-division link systems and also to some time-division switches of current interest. In the case of random hunting, the new models give improved agreement with simulation results. The overestimate of loss inherent in the Jacobaeus method, however, is found to be acceptably low when the numbers of primary and tertiary matrix switches are not small, e.g. > 10. We lack a good analytical model for the sequential hunting method, which is found to result in lower traffic loss for the switches being studied.

Efficient Algorithm for the Partitioning of Trees *by J. A. Lukes, p. 217.* This paper describes an algorithm for partitioning a graph that is in the form of a tree. The algorithm has a growth in computation time and storage requirements that is directly proportional to the number of nodes in the tree. Several applications of the algorithm are briefly described. In particular it is shown that the tree partitioning problem frequently arises in the allocation of computer information to blocks of storage. Also, a heuristic method of partitioning a general graph based on this algorithm is suggested.

Photolithography in Integrated Circuit Mask Metrology *by H. R. Rottmann, p. 225.* Photoresist technology is shown to have important advantages over the use of high-resolution silver halide films in dimensional metrology for integrated circuit masks. Experimental techniques are shown for the use of photoresist and chrome images in the study of image quality and uniformity and in analysis of the causes of image degradation. This method is applied to *in situ* lens evaluation and to the measurement of the precision of photorepeater stepping tables used in mask fabrication. In addition, the value of 0.3 μm is established as the practical limit of dimensional tolerance in the present photolithographic technology, and its significance to the advancement of the state of the art in mask manufacture is discussed.

Analysis of an AC Gas Display Panel *by C. Lanza, p. 232.* The details and results for a one-dimensional numerical analysis of the gaseous discharge occurring at a single intersection of an ac gas panel are reported. A particular object of the program is the determination of the electric field magnitude as a function of both position and time, taking into account the field distortion due to the space charge. The calculations are based on the Townsend avalanche mechanism but omit the dynamic role of metastable neon atoms in a Penning gas mixture. The calculated electrical properties of the panel are compared with experimental values.

Simulation of Cyclic Operation of a Gas Panel Device *by F.-M.-T. Lay, C.-K. Chu, and P. H. Haberland, p. 244.* This paper presents a numerical simulation model for the operation of a gas panel discharge cell with a neon-argon mixture. The model is based on a Townsend avalanche or direct ionization mechanism and secondary emission, as well as Penning collisions or indirect ionization. Charges on the dielectric walls are included, but space-charge field distortion is neglected. Cyclic operation of the cell is studied in detail and the effects of geometric and electrical parameters (e.g., gap and pulse widths) on the operating characteristics of the cell (e.g., write, sustain and erase voltages) have been obtained. The results are in good agreement with experimental data where available.

On Proving Correctness of Microprograms *by A. Birman, p. 250.* This paper describes the results of an investigation in proving the correctness of microprograms. The vehicle used is the S-machine, which is a very simple "paper" computer. The approach to the proof of correctness is based on formally defining the machine-instruction level and the microprogramming level of the given machine, and then showing that these "interfaces" are equivalent through the use of a concept called algebraic simulation.

Channel Equalization Using a Kalman Filter for Fast Data Transmission *by D. Godard, p. 267.* This paper shows how a Kalman filter may be applied to the problem of setting the tap gains of transversal equalizers to minimize mean-square distortion. In the presence of noise and without prior knowledge about the channel, the filter algorithm leads to faster convergence than other methods, its speed of

convergence depending only on the number of taps. Theoretical results are given and computer simulation is used to corroborate the theory and to compare the algorithm with the classical steepest descent method.

Stress Analysis of Glass-Bonded Ferrite Recording Heads *by T. Tang, p. 274.* Glass-bonded ferrite recording heads are subject to appreciable thermal stress because of the difference in thermal expansion between glass and ferrite in the temperature range of the glassing cycle. A theoretical analysis reveals the complexity of stress distributions in the structure and pinpoints the critically stressed areas in which a potential fracture or a magnetic degradation of the material may occur. It is found that the stresses are sensitive not only to the thermal mismatch of the component materials but also to the structural configuration. Low stress levels can be achieved by matching expansions of the materials and by proper head design, particularly in the optimization of fillet angle and fillet height.

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Optimal Pricing for an Unbounded Queue *by D. W. Low, p. 290.* The maximization of expected reward is considered for an $M_x/M/s$ queuing system with unlimited queue capacity. The system is controlled by dynamically changing the price charged for the facility's service in order to discourage or encourage the arrival of customers. For the finite queue capacity problem, it has been shown that all optimal policies possess a certain monotonicity property, namely, that the optimal price to advertise is a non-decreasing function of the number of customers in the system. The main result presented here is that for the unlimited capacity problem, there exist optimal stationary policies at least one of which is monotone. Also, an algorithm is presented, with numerical results, which will produce an ε-optimal policy for any $\varepsilon > 0$, and an optimal policy if a simple condition is satisfied.

Effects of Serial Programs in Multiprocessing Systems *by W. F. King III, S. E. Smith, and I. Wladawsky, p. 303.* A model of a multiprocessing, multiprogramming computer system with serially reusable programs was developed to study the effect of serial programs on system performance. Two strategies for implementing serially reusable programs were investigated, a *wait* strategy in which the processor waits until the serial program is available, and a *switch* strategy, in which the processor is freed to do other work. Relative performances and asymptotic conditions as functions of the number of processors, processes, serially reusable programs, and the fraction of time each process executes serially reusable programs were obtained. Quantitative results are presented showing that the switch strategy is superior. The wait strategy causes quick saturation when the number of processes is increased.

Optimal Task Switching Policy for a Multilevel Storage System *by T. Kaneko, p. 310.* Capacity demands for computer memory are increasing. A multilevel storage system provides an economically feasible solution without seriously affecting the total response time. An *M*-level storage system is considered in this paper. The capability of a digital computer with a multilevel storage system is best enhanced in a multiprogramming environment. In a high level storage system, determination of a best task switching policy becomes an important consideration. in this paper a queuing network is introduced to describe distribution and flow of tasks in the system. An optimal switching policy is determined in relation to the system's overhead time. It is shown that in heavily CPU-limited cases the determination becomes a very simple one; namely, the best policy is given as the threshold level at which the accumulation of the average access time exceeds the overhead time.

Determining Hit Ratios for Multilevel Hierarchies *by J. Gecsei, p. 316.* The applicability of stack processing for evaluation of storage hierarchies has been limited to two-level systems and to a very special group of multilevel hierarchies. A generalization of stack processing, called joint stack processing, is introduced. This technique makes possible the efficient determination of hit ratios for a class of multilevel hierarchies—staging hierarchies. These hierarchies are rather realistic in the sense that they allow for multiple block sizes and multiple copies of data in the hierarchy. Properties of storage management schemes that lend themselves to joint stack processing are studied, and the notion of distributed hierarchy management is described and illustrated.

Iterative-Interactive Technique for Logic Partitioning *by M. Hanan, A. Mennone, and P. K. Wolff, Sr., p. 328.* A method is developed for partitioning a computer logic design into subsets by combining a constructive method, used for the initial partition, with iterative improvement techniques. These iterative techniques are implemented in an interactive computing environment, which further enhances their efficiency and usefulness. An overview of the system is presented, several algorithms discussed and experimental results given.

Microcoded Modem Transmitters *by M. F. Choquet and H. J. Nussbaumer, p. 338.* This paper describes various microcoded designs for modem transmitters. The digital echo modulation technique, originally introduced by J-M. Pierret, is applied to cover the case of a fully digital universal modem. The capabilities of several microcoded modem designs are presented and their limitations are discussed.

Quantitative Electron Microprobe Analysis of Thin Films on Substrates *by D. F. Kyser and K. Murata, p. 352.* Monte Carlo simulation procedure is developed for kilovolt electron beam scattering and energy loss in targets consisting of thin films on thick substrates. Such calculations have direct application to the nondestructive quantitative chemical analysis of ultra-thin films in the electron microprobe (an electron probe x-ray microanalyzer), utilizing characteristic

x-ray fluorescence. Angular elastic scattering is calculated in the electron trajectory simulation with the screened Rutherford expression for cross section, and energy loss between elastic scattering events is calculated with the continuous-slowing-down approximation of Bethe. The contribution to x-ray fluorescence from the film due to backscattered electrons from the substrate is accounted for.

For elemental films, the Monte Carlo simulation predicts intensity ratios k_i, for characteristic x-rays from the film, referenced to standards of thick elemental samples. No film standards are required, and the mass thickness of any elemental film on any substrate can be determined from theoretical calibration curves. The model has been verified by measurements on films of Si, Cu, and Au on Al_2O_3 over wide ranges in E_0, and t. For alloy films, calibration curves are generated and graphically iterated to provide independent analysis of weight fractions C_i and total mass thickness ρt. Films of Mn_xBi_y and Co_xPt_y were successfully analyzed with $\rho t \leq 100\ \mu g/cm^2$.

Drop Formation in a Liquid Jet *by H. C. Lee, p. 364.* A one-dimensional analysis of drop formation in a liquid jet is developed under the assumption that the axial velocity of the axisymmetric, nonviscous liquid jet remains independent of the radial coordinate. The resulting equations are used for both linear and nonlinear analyses. In the linear form, this model provides a stream stability relation comparable to that of Rayleigh; transient solutions are obtained for given initial conditions of an infinite stream. For the nonlinear equations, numerical simulation was done to study the satellite drop formation; with the present model, the satellite drop is always formed.

Bulk Queue Model for Computer System Analysis *by W. Chang, p. 370.* A bulk queue model was developed for analyzing a multiprogrammed computer system. It can be used in conjunction with closed queuing models to study message queuing in a teleprocessing system. The model is based on an imbedded Markov chain analysis.

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Interatomic Potentials and Defect Energetics in Dilute Alloys *by P. S. Ho and R. Benedek, p. 386.* Effective interatomic potentials for impurities in aluminum have been constructed according to pseudopotential theory. Based on a local model potential, impurity valence and size factors are defined and their effects on the potential discussed. With these potentials, detailed calculations based on a Green's function lattice statics method are made for the impurity-vacancy binding energy and the difference in diffusion activation energies for an impurity and a host atom.

Within the range of valence and size factors studied, it is found that the binding energy is generally small and depends primarily on the valence rather than the size, whereas the migration energy shows larger increases with both valence and size factors. Contributions from the lattice relaxation energies are important, particularly for impurity migration. The results can account satisfactorily for the experimental data of nontransition-metal impurities, but less so for the noble-metal impurities. Dielectric screening of the ion by the conduction electrons is important in determining the potential and must be properly accounted for in calculations of the energetics for impurities.

Steady Solution for Circumferentially Moving Loads on Cylindrical Shells *by D. B. Bogy, H. J. Greenberg, and F. E. Talke, p. 395.* The steady, forced-wave solution is obtained for loads that travel with constant speed on a simply supported circular shell, the motion of which is damped externally by air. Critical speeds are identified above which the waveform, which is a standing wave in moving coordinates, exhibits shorter wavelengths in front of the load than behind it. At supercritical speeds the solution becomes unbounded, because of loss of stability, in the limit of no damping.

Equivalence of Memory to "Random Logic" *by W. E. Donath, p. 401.* A model of the design process for computer logic is used to estimate the number of bits of memory required to replace a so-called "random logic" circuit. The model can also be used to compare the respective time delays of array logic and random logic.

String Path Search Procedures for Data Base Systems *by S. P. Ghosh and M. E. Senko, p. 408.* This paper structures algorithms for the translation of set theoretic queries into procedures for the search of arbitrary complex networks constructed on a data base using three basic types of strings. A method for parameterization of queries which is appropriate for accessing string structures is outlined and it is shown how the properties of string structures can be used to construct an algorithm for finding a search path with minimum path cardinality for a given query addressed to such a network. (The term data management system is used instead of data base management system.)

Analysis of Exception Data in a Staging Hierarchy *by D. P. Gaver, P. A. W. Lewis, and G. S. Shedler, p. 423.* This paper is an analysis of program address trace data in a demand-paged computer system with a three-level staging hierarchy. Our primary objective is to explore the data both graphically and numerically, using methods that may be useful when other data traces become available. In addition, plausible point-process type models are fit to the data. Such an approach, combining data-analytic procedures with probability modeling, should prove useful in understanding program behavior and thus will aid in the rational design of complex computer systems.

Structure Dependence of Free-Charge Transfer in Charge-coupled Devices *by W. H. Chang and L. G. Heller, p. 436.* A detailed numerical analysis of

charge-coupled-device (CCD) charge transfer is described and discussed. The analysis is based on solving the transport equation with a time-dependent surface field calculated from the actual device configuration. Devices with different oxide thicknesses and devices with electrode gaps are examined. The total field is found to play an important role in charge transfer for all cases studied. The effective channel length is modulated by the net field present and is a function of time and electrode configuration. The transfer is found fastest and the effective channel length shortest when the charge is transferred from a region of low oxide capacitance into a region of high oxide capacitance. A low-capacitance electrode gap slows the charge transfer process.

MINI: A Heuristic Approach for Logic Minimization *by S. J. Hong, R. G. Cain, and D. L. Ostapko, p. 443.* MINI is a heuristic logic minimization technique for many-variable problems. It accepts as input a Boolean logic specification expressed as an input-output table, thus avoiding a long list of minterms. It seeks a minimal implicant solution, without generating all prime implicants, which can be converted to prime implicants if desired. New and effective subprocesses, such as expanding, reshaping, and removing redundancy from cubes, are iterated until there is no further reduction in the solution. The process is general in that it can minimize both conventional logic and logic functions of multi-valued variables.

Generating Test Examples for Heuristic Boolean Minimization *by D. L. Ostapko and S. J. Hong, p. 459.* This article describes simple methods of generating many-variable test-case problems for heuristic logic minimization studies. Covering problems and coloring problems are converted into Boolean functions that are useful test cases for minimization.

Addendum to "Loss of Point-to-Point Traffic in Three-State Circuit Switches" *by M. Karnaugh, p. 465.*

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Preface *by H. B. Michaelson, p. 479.*

Aerodynamic Aspects of Disk Files *by E. Lennemann, p. 480.* Airflows between centrally clamped, rotating, rigid disks are investigated with respect to the type of flow pattern, the parameters that influence nonuniform flow, and the effects of various flow patterns on disk stability. The experimental method uses a water-flow modeling technique for the airflow. The observed flow patterns are highly unsteady. The configuration and position of the shroud and slider arm are found to be the major parameters that influence flow characteristics. A reduction of disk flutter by a factor of 12 can be achieved when the unsteady flow pattern is changed to a steady flow pattern.

Engineering Design of a Disk Storage Facility with Data Modules *by R. B. Mulvany, p. 489.* The design of the IBM 3340 Direct Access Storage Facility with IBM 3348 Data Modules incorporates new concepts and required the development of several innovative components, including newly designed magnetic read-write heads. The heads start and stop in contact with the disk and use a tri-rail, air-bearing slider having a low mass. Each data module includes read-write heads, a head carriage, disks, and a disk spindle.

The rationale is discussed for the design concepts and for several components, including the data module, head and arm assembly, and the moving-coil linear actuator. A method of improving data integrity, utilizing a "disk-defect skipping" procedure, is described and its performance implications discussed.

Design of a Disk File Head-Positioning Servo *by R. K. Oswald, p. 506.* The engineering design of a head-positioning system for an interchangeable-medium disk file is considered. Emphasis is placed upon three specific functions within the positioning system: (1) encoding and demodulation of information from the dedicated servo surface, (2) compensation and dynamics of the track-following control system, and (3) implementation of control electronics for a quasi-time-optimal, track-accessing control system. The examples used are taken from the IBM 3340 Disk Storage Facility.

Dynamic Response of Self-acting Foil Bearings *by K. J. Stahl, J. W. White, and K. L. Deckert, p. 513.* A new approach to the analysis of wide foil bearings is investigated. The equation of motion for a finite length of tape is coupled to the transient lubrication equation for the air film between the tape and the recording head. Compressibility and slip flow are retained in the fluid mechanics equation; flexural rigidity and high-speed dynamic effects are retained in the tape equation. The steady-state solution to the coupled equations is obtained as the limiting case of the transient initial value problem. Describing the system equations relative to the undeflected tape (as opposed to conventional foil-bearing theory, which uses the head as the reference surface) permits investigation of noncircular head geometries. In addition, wave propagation effects in the tape and the interaction of waves in the tape with the air-bearing region may be studied.

White Light Interferometry of Elastohydrodynamic Lubrication of Foil Bearings *by S. M. Vogel and J. L. Groom, p. 521.* This paper describes an experiment performed to verify the one-dimensional model of elastic foil behavior developed by Stahl, White, and Deckert. In the experiment, a loop of tape one-inch wide passes over a stationary recording head, and the air-film thickness between the head and the foil is determined using white light interferometry. Measured data for various experimental conditions are compared with the predictions of the model and also with prior foil-bearing analyses. The influence of parameters such as tape thickness, head radius, tape tension, etc. on the nature of the spacing field is demonstrated.

Infrared Laser Interferometer for Measuring Air-bearing Separation *by J. M. Fleischer and C. Lin, p. 529.* The design and characteristics are presented for an infrared instrument capable of measuring air-bearing separation distances over a mechanical bandwidth ranging from dc to 30 kHz. The measurement technique involves monitoring optical intensity variations of the interferometric cavity formed by two air-bearing surfaces. This intensity varies between a minimum at zero separation and a maximum at a distance equal to one-quarter of the optical wavelength. For air-bearing distances less than 1 μm, a convenient source is the 3.391 μm infrared line of the helium-neon laser. By continually monitoring a fraction of the intensity of the optical source, a real-time analog division can be performed on the spacing signals to produce an output independent of laser intensity variations. Room-temperature indium arsenide detectors were selected for their high responsivity and rapid rise time.

Transition from Boundary Lubrication to Hydrodynamic Lubrication of Slider Bearings *by R. C. Tseng and F. E. Talke, p. 534.* The transition from boundary lubrication to fully hydrodynamic lubrication is investigated for air-lubricated slider bearings using the electrical resistance method. Intermittent contacts are shown to exist even under conditions for which the numerical solution of the Reynolds equation or white light interferometry predicts steady state spacings in the spacing region from 0.125 to 0.25 μm. The transition is similar to the one found in the presence of liquid films, being influenced for a given surface roughness of disk and slider by load, speed, and hydrodynamic design.

Hand-held Magnetoresistive Transducer *by C. H. Bajorek, C. Coker, L. T. Romankiw, and D. A. Thompson, p. 541.* The initial design of a vertical magnetoresistive head in a hand-held wand for reading magnetically encoded price tags and credit cards is discussed. The performance of the head (e.g., resolution, signal shape and amplitude, and signal-to-noise ratio) is analytically and experimentally evaluated as a function of the configuration of the sensor, head-to-medium interface, and sensor processing and materials.

Thermally Induced Pulses in Magnetoresistive Heads *by R. D. Hempstead, p. 547.* The thermal response of a magnetoresistive head is analyzed for frictional heating between the head surface and dust particles or other asperities on the recording medium surface during relative motion of head and medium. A theoretical model is presented showing that pulses are induced in the output of a magnetoresistive head as a result of this frictional heating. The model predicts the dependence of these noise spikes on the thermal properties of the substrate and cover chip for the magnetoresistive head, the dimensions of the magnetoresistive stripe, the head-medium relative velocity, and the rate of frictional heat generation. Experimental verification of the theoretical model is obtained by scanning a focused laser beam across a head.

Numerical Analysis of the Shielded Magnetoresistive Head *by R. W. Cole, R. I. Potter, C. C. Lin, K. L. Deckert, and E. P. Valstyn, p. 551.* Numerical computations for the shielded magnetoresistive head are reported and compared with previous analytic and experimental results. Linear resolution is found to be essentially the same as for inductive heads. Output amplitude is in the range 50 to 175 V per meter track width for a sense current density of 5×10^{10} A/m^2.

Ferrite Film Recording Surfaces for Disk Recording *by R. L. Comstock and E. B. Moore, p. 556.* Ferrite thin films have been prepared using a chemical deposition process; hematite and substituted hematite films were formed by spin coating a diluted solution of the metal nitrates on a substrate and subsequently heating the substrate in air to 300°C to crystallize the film. Magnetic ferrite films were formed by reducing the films in a wet hydrogen atmosphere. Process parameters, which have evolved from studies on spin coating and reduction on 7.62- and 35.56-cm substrates, have been determined that result in desirable magnetic properties. Experimental studies of film composition and morphology are reported. It has been determined both theoretically and experimentally that film thickness near 0.125 μm is optimum for high-density recording with heads with gap lengths of approximately 1 μm spaced about 0.5 μm from the film. A TiO_2 undercoat (0.125 μm) on the Al-Mg alloy substrate was prepared by chemical vapor deposition and resulted in improved magnetic properties. Magnetic properties of the films and magnetic recording performance of disks using Ti and Al substrates with the TiO_2 undercoat are reported.

The Remanent State of Recorded Tapes *by G. Bate and L. P. Dunn, p. 563.* Measurements are reported on the in-plane and the perpendicular components of the remanence a tape acquires on passing through the steady field of a recording head. The tape coatings were oriented and unoriented particles of γ-Fe_2O_3, oriented CrO_2 and unoriented Co-substituted γ-Fe_2O_3. The two writing heads used had 10μm- and 2.25μm-gaps, respectively. In each case the in-plane magnetization increases at first with increasing writing current, and eventually reaches a peak that is less than the maximum in-plane remanence produced on the same sample by an electromagnet. For higher values of writing current, in-plane magnetization in the tape actually decreases. The perpendicular remanence is not large enough to explain the difference between the in-plane remanence acquired from the head and the remanence acquired in a magnet.

The perpendicular component of the field from the writing head is shown to have two adverse effects on the remanence of the tape. First, it produces a perpendicular magnetization that ranges from 2 percent to 15 percent of the in-plane component. Second, it causes a reduction in the in-plane component to occur near the surface of the tape closest to the writing head. The reduction can be as large as 15 percent of the maximum in-plane remanence and will obviously have an

adverse effect on recording performance, particularly at high densities.

Noise in Disk Data-recording Media *by J. L. Su and M. L. Williams, p. 570.* Measurements were made of recording medium noise in erased disks using an in-contact magnetoresistive element and an inductive head supported on an air bearing slider. Four types of coatings on aluminum disks were examined: thin, transition-metal alloy film, CrO_2, FeCo particle, and γ-Fe_2O_3. Results obtained by means of three measurement techniques are in qualitative agreement and indicate that: (1) dc-erased noise of alloy film disks is 14 to 20 dB lower than that of particulate disks measured; (2) dc-erased noise of particulate disks measured is 6 to 16 dB above their bulk-erased noise; (3) although dc noise of particulate disks increases with write current, dc noise of alloy film disks is independent of write current; (4) the shapes of the noise spectra are similar in dc-erased particulate γ-Fe_2O_3 disks and FeCo particle coated disks; and (5) significant modulation noise is detected on particulate disks but not on alloy film disks. The observed dc-erased noise spectrum is compared with the model for small particle noise and is then used to estimate the size of particle agglomerates or voids.

Switching Speeds in Magnetic Tapes *by R. F. M. Thornley and J. A. Williams, p. 576.* Comparative measurements are reported on the switching speeds of three different magnetic tape materials, as determined by application of short field pulses of well-defined duration and magnitude. A sensitive measure of the change in magnetization is the length of applied pulse required for the peak readback signal to drop from 60 percent to 40 percent of its peak value. This pulse length was 2.6 ns for a γ-Fe_2O_3 tape, 4.1 ns for a CrO_2 tape, and 1.4 ns for a cobalt-substituted γ-Fe_2O_3 tape.

Optimal Rectangular Code for High Density Magnetic Tapes *by A. M. Patel and S. J. Hong, p. 579.* IBM's 6250 bpi 3420 series tape units require a powerful error-correcting code for the standard 9-track format. The optimal rectangular code (ORC), presented here, is designed to correct any single-track error or, given erasure pointers, any double-track error in the tape. The code achieves this by conforming to a rectangular codeword of which two orthogonal sides are check bits. The code is specially tailored from a general class of *b*-adjacent codes. The ORC can be implemented without a buffer for encoding and offers a simple error-correction mechanism. The code can be generalized to multiple-channel applications.

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Approximating Complex Surfaces by Triangulation of Contour Lines *by E. Keppel, p. 2.* An algorithm is described for obtaining an optimal approximation, using triangulation, of a three-dimensional surface defined by randomly distributed points along contour lines. The combinatorial problem of finding the best arrangement of triangles is treated by assuming an adequate objective function. The optimal triangulation is found using classical methods of graph theory. An illustrative example gives the procedure for triangulation of contour lines of a human head for use in radiation therapy planning.

Stream Processing Functions *by W. H. Burge, p. 12.* One principle of structured programming is that a program should be separated into meaningful independent subprograms, which are then combined so that the relation of the parts to the whole can be clearly established. This paper describes several alternative ways to compose programs. The main method used is to permit the programmer to denote by an expression the sequence of values taken on by a variable. The sequence is represented by a function called a *stream,* which is a functional analog of a coroutine. The conventional **while** and **for** loops of structured programming may be composed by a technique of stream processing (analogous to list processing), which results in more structured programs than the originals. This technique makes it possible to structure a program in a natural way into its logically separate parts, which can then be considered independently.

Scheme for Invalidating References to Freed Storage *by D. B. Lomet, p. 26.* A storage management scheme is described that supports the invalidation of addresses to freed storage and thus, in that sense, provides a secure system. Unlike previous virtual memory techniques, the allocated areas of our scheme can vary from the very large, requiring multiple pages of storage, to the very small, in which several can be contained on a single page. Special treatment is accorded procedure activation storage so as to provide increased effectiveness for this important case. The interaction of this deletion scheme with garbage collection techniques is also examined. Finally, the relative advantages of retention and deletion strategies of storage management are considered.

Parametric Analysis of Queuing Networks *by K. M. Chandy, U. Herzog, and L. Woo, p. 36.* We consider a queuing network with M exponential service stations and with N customers. We study the behavior of a subsystem σ, which has a single node as input and a single node as output, when the subsystem parameters are varied. An "equivalent" network is constructed in which all queues except those in subsystem σ are replaced by a single composite queue. We show that for certain classes of system parameters, the behavior of subsystem σ in the equivalent network is the same as in the given network. The analogy to Norton's theorem in electrical circuit theory is demonstrated. In addition, the equivalent network analysis can be applied to open exponential networks.

Approximate Analysis of General Queuing Networks *by K. M. Chandy, U. Herzog, and L. Woo, p. 43.* An approximate iterative technique for the analysis of complex queuing networks with general service times is presented. The technique is based on an application of Norton's theorem from electrical circuit theory to queuing networks which obey local balance. The technique determines approximations of the queue length and waiting time distributions for each queue in the network. Comparison of results obtained by the approximate method with simulated and exact results shows that the approximate method has reasonable accuracy.

Device Design Considerations for Ion Implanted n-Channel MOSFETs *by V. L. Rideout, F. H. Gaensslen, and A. LeBlanc, p. 50.* Device design considerations are presented for ion implanted, n-channel, polysilicon gate, enhancement-mode MOSFETs for dynamic switching applications. A shallow channel implant is used to raise the magnitude of the gate threshold voltage while also maintaining a low substrate sensitivity (i.e., without substantially increasing the dependence of the threshold voltage on the source-to-substrate "backgate" bias). Design trade-offs between channel implantation energy and dose and substrate bias were examined using both computer analyses and experimental devices. The design objective was to identify the combination of these three parameter values that gives both a low substrate sensitivity and a steep subthreshold conduction characteristic under the conditions of a gate threshold voltage of 1 V and a substrate bias range of 0 to -1 V. One-dimensional and two-dimensional computer analyses were performed to predict the effect of the device parameters on the electrical characteristics. MOSFETs were then fabricated to investigate the extremes of the design parameter range, and the experimental and predicted device characteristics were compared. An enclosed device structure proved particularly useful in evaluating the subthreshold characteristic at very low values of drain current.

Keyboard Method for Composing Chinese Characters *by E. F. Yhap, p. 60.* A keyboard method is described that allows a user to form Chinese characters. The user's keystrokes activate internal logic, which performs the necessary scaling and positioning of the character components. An initial design using a 40-key keyboard is described, together with approximations of the character shapes produced by given keying sequences. Rough estimates of speed range from eight to 33 characters per minute.

Segment Synthesis in Logical Data Base Design *by C. P. Wang and H. H. Wedekind, p. 71.* Identification and representation of entities and their relationships relevant to an application are some of the key problems in logical data base design. This paper presents an approach to synthesizing

logical segments that are representations of such entities and relationships. The major steps in this design are 1) collect all the pertinent functional relations in the application domain; 2) remove redundant relations to obtain a minimal covering set; 3) minimize the number of relations in the covering set to obtain an optimal set of relations in the third normal form; and 4) combine relations into logical segments according to prescribed performance requirements and projected information maintenance activities. Synthesis of logical segments for an airline reservations application is used as an illustrative example.

Composite Priority Queue *by T. W. Gay and P. H. Seaman, p. 78.* This paper presents formulas for calculating waiting time for customers in a queue with combined preemptive and head-of-line (nonpreemptive) priority scheduling disciplines and describes the reasoning behind them. This work has been applied in the development of programmable terminal control units.

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An Introduction to Array Logic *by H. Fleisher and L. I. Maissel, p. 98.* After a discussion of the reasons for choosing to implement logic in array form, a detailed description of the nature of array logic is given. Topics specifically discussed include general array structures and implementation, influence of decoder partitioning, design of logic arrays, output phase, "split" variables, feedback in logic arrays, and reconfiguration.

Hardware Implementation of a Small System in Programmable Logic Arrays *by J. C. Logue, N. F. Brickman, F. Howley, J. W. Jones, and W.-W. Wu, p. 110.* Large Scale Integration, LSI, is the means by which digital circuits have achieved remarkable manufacturing cost reductions but, unfortunately, at the expense of higher engineering design costs. Programmable Logic Arrays, PLAs, exploit many of the benefits of LSI but without the high engineering design costs. This paper describes an experiment in the design and implementation of a small complex system in array logic. The IBM 7441 Buffered Terminal Control Unit was selected for this comparison because it is a small but complex terminal controller implemented in dual in-line packaged transistor logic, DIP-TL, with small to medium scale integration.

Array Logic Macros *by J. W. Jones, p. 120.* A macro design approach is discussed which combines the cost-effective attributes of array logic structures with those of random logic. These macros utilize the following features: (a) internal feedback registers for performing sequential logic, (b) masking and submasking to reduce the number of words in the array for certain functions, (c) control of the array's output level to vary the apparent size of the array, (d) decoding on input pairs and/or EXCLUSIVE ORing on output pairs for increasing the number of logic levels, and (e) random-access memory in the feedback and its use in interrupt handling. The macros are explained by specific design examples. This paper also discusses standard logic circuits in combination with an array structure to produce a component that can be used efficiently in specific data processing areas. The designer may elect to define an array logic macro which is a combination of some of the features given in this paper. The guideline for this selection is based upon the features necessary in an array structure to be competitive with a random logic LSI chip.

Polarization and Depolarization in PSG Films *by L. Kasprzak and A. Hornung, p. 127.* The temperature dependence of the polarization in thin phosphosilicate glass (PSG) films is characterized by an activation energy $\Delta H = (0.39 + 0.039Et)$ eV, whereas the decay mechanism has an activation energy of 0.5eV. The flatband voltage shift due to PSG polarization was linear with applied fields as large as $5.5 \times 10^6 V \cdot cm^{-1}$. The effective time constants for the polarization and depolarization are distinctly different. Polarization occurs an order of magnitude faster than depolarization. A physical model has been postulated to explain the observed effects.

Storage Hierarchy Optimization Procedure *by J. E. MacDonald and K. L. Sigworth, p. 133.* The goal of storage hierarchies is to combine several storage technologies in such a way as to approach the performance of the fastest component technology and the cost of the least expensive one. This paper presents optimization techniques for a storage hierarchy subject to quantity-sensitive component costs. It is assumed that a finite (and probably small) set of technologies is available. Each technology is characterized by an access time and two cost parameters. We assume that statistical summaries of address sequences are available. We present solutions to four problems of increasing complexity: 1) minimization of access time for a fixed cost and preassigned page sizes; 2) optimization of a generalized price-performance function under preassigned page sizes; 3) minimization of access time for a fixed cost when page sizes are allowed to vary; 4) optimization of a generalized price-performance function when page sizes are allowed to vary.

Block-oriented Information Compression *by H. Ling and F. P. Palermo, p. 141.* Data base statistics play an important role in conventional information compression. For a large data base, the acquisition of data base statistics becomes a very difficult task. This paper presents a new scheme for information compression that does not use information statistics. Each information block is represented by two sub-blocks called the *alphabet* and the *generator*. The *alphabet* contains the linearly independent elements; the *generator* is computed through the linear combination of the linearly dependent elements. The total length of these two sub-blocks is generally shorter (never greater) than the original block.

High Speed Transistor with Double Base Diffusion *by S. Magdo and I. Magdo, p. 146.* A high speed bipolar transistor has been fabricated by using double base diffusion to reduce

the base resistance R_B. The base resistance forms two important time constants, R_BC_D and $R_BC_C(R_I/R_E)$ with the emitter diffusion capacitance C_D and collector capacitance C_C dominating the switching delay of the circuits. We demonstrate that the base resistance of a single base diffused device can be reduced by a factor of four by using double base diffusion without affecting its cut-off frequency $f_t = 7$ GHz. The double base diffusion also increases the punchthrough voltage of the device from 3 to 7V.

On Dislocations in $GaAs_{1-x}P_x$ *by S. Mader and A. E. Blakeslee, p. 151.* Misfit dislocations in epitaxially grown layers of $GaAs_{1-x}P_x$ with a lattice constant gradient are examined by transmission electron microscopy. In specimens with (113) A growth planes, they form a three-dimensional arrangement of glissile and sessile dislocations. Cross slip is an important process in the generation of the dislocations. High resolution microscopy shows 1) glissile dislocations dissociated into partial dislocations and 2) undissociated sessile Lomer dislocations. These differences are attributed to contributions to the dislocation core energy from wrong bonds and dangling bonds. Screw dislocations are also thought to be undissociated, which facilitates cross slip and multiplication of dislocations.

What Is a Multilevel Array? *by A. L. Rosenberg and J. W. Thatcher, p. 163.* In intuitive terms, a multilevel array is either a scalar or an array each of whose elements is a multilevel array. The "semantics" of multilevel arrays can be easily expressed in terms of a notion of selector, which is basically that of the Vienna Definition Language. These selectors provide both a notational device for accessing multilevel arrays and a clean mathematical definition of "multilevel array with data domain *D*." However, the definition so obtained lacks the recursive flavor of the intuitive definition. By means of an axiomatic characterization of multilevel arrays, the selector-based definition and the recursive definition are shown to be equivalent.

Combinatorial Solution to the Partitioning of General Graphs *by J. A. Lukes, p. 170.* This paper reviews a dynamic programming procedure for the partitioning of connected graphs with integer-weighted nodes and positive valued edges. The upper bound on the number of feasible partitions generated using this technique is shown to grow factorially in the number of graph nodes. The use of graph properties is then introduced to reduce the number of feasible partitions generated in the determination of the optimal partition. Depending upon the structure of the graph, the use of these properties can cause a significant reduction in the computation time and storage space required to partition the graph.

Automatic Structuring of Programs *by G. Urschler, p. 181.* A method is described that allows the translation of a traditionally written (unstructured) program into a set of top-down structured, semantically founded, GOTO-free modules. The method reveals not only the logic of a given program in a most natural way, but it also reduces code duplication to a minimum. It is further shown how the obtained structured program can be mapped back into a GOTO program in such a way that all GOTOs are backwards branches and their number is minimal. The connection between recursively and iteratively structured programs is demonstrated using the WHILE, DO FOREVER, and multilevel EXIT statements. Extensions of the method show the structuring of source programs containing block structures and subroutines.

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Preface *by R. Ashany, p. 210.*

Application of the Page Survival Index (PSI) to Virtual-memory System Performance *by Y. Bard, p. 212.* The Page Survival Index (PSI) was defined in a preceding paper where it was used to describe the behavior of individual programs running in a time sharing environment. Here we show how a system-wide value of PSI can be calculated on the fly by the operating system. This value can be used to estimate users' memory requirements and to control system performance by maintaining the proper multiprogramming level. Simulation results show that a scheduler based on these concepts can achieve significant improvements in system performance.

Predicting Working Set Sizes *by P. Bryant, p. 221.* Empirical analyses of data on working set size are reported. The data do not support the hypothesis that working set sizes are normally distributed. The data suggest various algorithms for predicting working set size based on the program's past history. Several representative algorithms are discussed and evaluated.

Patterns in Program References *by W. F. Freiberger, U. Grenander, and P. D. Sampson, p. 230.* This paper describes a study of some of the characteristics of program referencing patterns. Program behavior is investigated by constructing stochastic models for the page reference mechanism and evaluating the validity of the assumptions made through comparison with empirical results. The notion of a regime process is shown to play a useful role in describing the observed phenomena mathematically. The study falls within the realm of a rapidly growing field of computer science known as compumetrics, where quantitative and qualitative methods are being applied to the study and evaluation of computer performance.

Tailoring Programs to Models of Program Behavior *by D. Ferrari, p. 244.* This paper considers the premise that, in addition to trying to solve the virtual-memory-system performance problem by devising a storage management strategy suitable for the broad spectrum of behavior exhibited by programs, efforts also be made to tailor the behavior of each program to the model underlying the storage

management strategy under which the program will have to run. It is observed that a viable approach to program tailoring is offered by restructuring techniques. The application of dynamic off-line techniques to the tailoring problem is discussed, and an algorithm which may be used to fit program behavior to the working set model is described in detail as an example. The performance of this algorithm in dealing with two real-program traces is experimentally evaluated under a variety of conditions and found to be always satisfactory.

Design of Experiments in Simulator Validation *by M. Schatzoff and C. C. Tillman, p. 252.* A common problem encountered in computer system simulation is that of validating that the simulator can produce, with a reasonable degree of accuracy, the same information that can be obtained from the modeled system. This is basically a statistical problem because there are usually limitations with respect to the number of controlled tests that can be carried out, and assessment of the fidelity of the model is a function of the signal to noise ratio. That is, the magnitude of error which can be tolerated depends upon the size of the effect to be predicted. In this paper we describe, by example, how techniques of statistical design and analysis of experiments have been used to validate the modeling of the dispatching algorithm of a time sharing system. The examples are based on a detailed, trace-driven simulator of CP-67. They show that identical factorial experiments involving parameters of this algorithm, when carried out on both the simulator and on the actual system, produced statistically comparable effects.

Performance Analysis of a Multiprogrammed Computer System *by W. Chiu, D. Dumont, and R. Wood, p. 263.* A combination of analytical modeling and measurement is employed for the performance analysis of a multiprogrammed computer system. First, a cyclic queue model is developed for the system under study. Then, model validation is attempted in both controlled and normal environments. The success of the model is demonstrated by its prediction of performance improvements from system reconfigurations. Reasonable correlation between the measured performance and the model predictions under various degrees of multiprogramming is observed. Finally, possible system reconfigurations are explored with the insight gained from the performance analysis.

Terminal Response Times in Data Communications Systems *by J. H. Chang, p. 272.* A response time analysis for a general class of terminals-to-computer subsystem is presented in this paper. The model used is based on the most advanced data communications system in which terminals are connected to Terminal Control Units (TCU) that are in turn connected to local Front-End Processors (FEP). The line control procedures used to interface a TCU and an FEP may be half-duplex Binary Synchronous Communications (BSC), half-duplex Synchronous Data Link Control (SDLC), or full-duplex SDLC. The models presented here can be used to determine bottlenecks in the entire system and to facilitate the initial phase of system design and configuration.

Queuing Networks with Multiple Closed Chains: Theory and Computational Algorithms *by M. Reiser and H. Kobayashi, p. 283.* In this paper a recent result of Baskett, Chandy, Muntz, and Palacios is generalized to the case in which customer transitions are characterized by more than one closed Markov chain. Generating functions are used to derive closed-form solutions to stability, normalization constant, and marginal distributions. For such a system with N servers and L chains the solutions are considerably more complicated than those for systems with one subchain only. It is shown how open and closed subchains interact with each other in such systems. Efficient algorithms are then derived from our generating function representation.

Solution of Queuing Problems by a Recursive Technique *by U. Herzog, L. Woo, and K. M. Chandy, p. 295.* A recursive method for efficient computational analysis of a wide class of queuing problems is presented. Interarrival and service times are described by multidimensional Markovian processes while arrival and service rates are allowed to be state dependent.

Approximate Analysis of Central Server Models *by C. H. Sauer and K. M. Chandy, p. 301.* Service time distributions at computer processing units are often nonexponential. Empirical studies show that different programs may have markedly different processing time requirements. When queuing disciplines are first come, first served, preemptive priority or nonpreemptive priority, models reflecting these characteristics are difficult to analyze exactly. Available approximate techniques are often too expensive for parametric analysis. Inexpensive approximate techniques for solution of central server models with the above characteristics are presented. The results of these techniques are validated with simulation results.

Central Server Model for Multiprogrammed Computer Systems with Different Classes of Jobs *by W.-M. Chow, p. 314.* A computer system can usually be interpreted as a closed network with two different types of servers. It is then possible to convert the network into a single server system with state-dependent arrivals. This paper investigates the stationary behavior of a single server queue with different classes of jobs. It is assumed that the input process has state-dependent exponential inter-arrival times and preemptions at the server are not allowed. The exact solution is obtained by finding the relationship between the time average probability distribution and the departure average probability distribution. The latter can be derived, based upon an imbedded Markov Chain.

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Vibrating Reed Internal Friction Apparatus for Films and Foils *by B. S. Berry and W. C. Pritchet, p. 334.* An apparatus

is described which permits for the first time the resolution of anelastic relaxation effects in evaporated metallic thin films and ion-implanted surface layers of silicon. The composite samples consist of the film or layer of interest on a carrier substrate having the form of a thin cantilevered reed. Low external losses and an exceptionally good span of operating frequencies are obtained by integrally bonding the substrate to a supporting pedestal and by using electrostatic drive and detection for the transverse modes of vibration. The internal friction can be measured with relatively simply instrumentation, at pressures below 10^{-5} torr (1.33×10^{-3} Pa) and over the temperature range −190°C to 550°C. The apparatus has considerable versatility for work in a number of areas, including the investigation of metallic foils prepared by splat-cooling.

Modular Hall Masterslice Transducer *by R. J. Braun, p. 344.* The Hall masterslice transducer combines modern IC (integrated circuit) technology with a modular design concept to provide a flexible multifunction approach to magnetic sensing. Its sensing element, a controllable Hall cell, is integrated with the associated circuitry on a masterslice chip, mounted in a flux concentrator module that forms the basic building block for diverse application packages. The device has several auxiliary control electrodes that allow fixed or externally variable offset voltage control and magnetic field simulation, as well as threshold, hysteresis, and gain adjustments. Integral flux concentrators provide the module with an efficient magnetic flux path and chip cooling. Three application categories—switches, proximity sensors, and current sensors—are discussed and various application package designs are presented.

LRU Stack Processing *by B. T. Bennett and V. J. Kruskal, p. 353.* Stack processing, and in particular stack processing for the least recently used replacement algorithms, may present computational problems when it is applied to a sequence of page references with many different pages. This paper describes a new technique for LRU stack processing that permits efficient processing of these sequences. An analysis of the algorithm and a comparison of its running times with those of the conventional stack processing algorithms are presented. Finally we discuss a multipass implementation, which was found necessary to process trace data from a large data base system.

Codes for Self-clocking, AC-coupled Transmission: Aspects of Synthesis and Analysis *by S. J. Hong and D. L. Ostapko, p. 358.* We consider NRZI waveform codes that satisfy a given set of run-length constraints and the upper bound on the accumulated dc charge of the waveform. These constraints enable the codeword to be self-clocking, ac-coupled, and suitable for data processing tape and communication applications. Various aspects of synthesis and analysis of such codes, called (d, k, C) codes, are illustrated by means of several examples. The choice of the initial state of the encoder is shown to influence the length of the data sequence over which the encoder must look-ahead.

Zero-Modulation Encoding in Magnetic Recording *by A. M. Patel, p. 366.* This paper deals with waveform encoding methods in which binary data are mapped into constrained binary sequences for shaping the frequency spectrum of corresponding waveforms. Short and long pulse widths in the waveform are limited by constraints on the minimum and maximum run-lengths of zeros in the coded sequences. These constraints reduce the intersymbol interference in magnetic recording and provide an adequate rate of transition for accurate clocking. Signal power at low frequencies is limited by means of a constraint on a parameter that corresponds to the maximum imbalance in the number of positive and negative pulses of the waveform. This constraint on the maximum accumulated dc charge also eliminates the zero-frequency component.

Zero modulation is one such code that is especially suitable for magnetic recording channels. The encoding and decoding algorithm is presented. A one-to-one correspondence between binary data and constrained sequences is established by creating data states that are isomorphic to the charge states having the same growth rate. Sequences with other values of run-length and charge constraint are examined as candidates for other codes with zero dc component.

High-Speed Dynamic Programmable Logic Array Chip *by R. A. Wood, p. 379.* This paper describes the circuit design of a programmable logic array chip using four-phase dynamic circuits, operating at a nominal cycle time of 230 nanoseconds. Bootstrap circuit techniques are used to obtain high function and performance by satisfying some special requirements of PLA designs. These include a simple means for two-bit partitioning of the data inputs, a noninverting buffer circuit between precharged arrays, and a fast, compact on-chip driver for heavily loaded arrays. Multiphase clocking enables the use of master/slave type JK flip-flops with minimum circuitry and power dissipation. A polarity hold function is provided at the outputs to allow interfacing the dynamic design to static output circuits.

Interpolation with Discontinuous Functions: Application to Calculation of Shocks *by W. L. Miranker and A. Morreeuw, p. 384.* An interpolation procedure, which uses a step function plus a polynomial correction, is devised and studied for application to the numerical solution of problems having discontinuous solutions. We apply the interpolation procedure to the calculation of shock waves produced by a single convex conservation law. The resulting algorithm does not have the usual undesirable numerical features associated with shock-wave calculations. The stability and convergence of the algorithm is also demonstrated.

Multifont OCR Postprocessing System *by W. S. Rosenbaum and J. J. Hilliard, p. 398.* A series of techniques is being

developed to postprocess noisy, multifont, nonformatted OCR data on a word basis to 1) determine if a field is alphabetic or numeric; 2) verify that an alphabetic word is legitimate; 3) fetch from a dictionary a set of potential entries using a garbled word as a key; and 4) error-correct the garbled word by selecting the most likely dictionary word. Four algorithms were developed using a technique called vector processing (representing alphabetic words as numeric vectors) and also by applying Bayes maximum likelihood solutions to correct the OCR output. The result was the development of a software simulator which processed sequential fields generated by the Advanced Optical Character Reader (in use by the U.S. Postal Service in New York City), performed the four functions indicated above, and selected the correct alphabetic word from a dictionary of 62,000 entries.

Ferromagnetism in Bi- and Te-substituted MnRh *by J. C. Suits, p. 422.* A series of experiments shows that substitution of Bi into antiferromagnetic MnRh causes this alloy to become ferromagnetic. The Curie temperature of $(Mn_{0.8}Bi_{0.2})$ Rh is 185K and the moment is $3.5\mu_B$ per formula unit. Substitution of Te instead of Bi gives similar results. This effect is consistent with a model of competitive ferromagnetic and antiferromagnetic exchange in MnRh-type compounds.

Comment on "Bulk Queue Model for Computer System Analysis" *by E. W. Stacy, p. 424.*

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Preface *by R. Ashany, p. 434.*

Computation of Lower Bounds for Multiprocessor Schedules *by E. B. Fernández and T. Lang, p. 435.* A multiprocessing system composed of identical units is considered. This system is executing a set of partially ordered tasks, with known execution times, using a non-preemptive scheduling strategy. Lower bounds on the number of processors required to compute the tasks before a deadline, and on the minimum time to execute the tasks with a fixed number of processors, are of great value for the determination of the corresponding optimal schedules. In this paper, methods for the efficient computation of the lower bounds obtained by Fernández and Bussell are discussed. Computational improvements for the case of general partial orders are reported, and further reductions of the number of operations are shown to be possible for special graphs (trees, independent chains, independent tasks).

Dynamic Partitioning of the Main Memory Using the Working Set Concept *by M. Z. Ghanem, p. 445.* An algorithm to divide the main memory among N competing programs with different characteristics, running in a multiprogramming and virtual memory environment, is proposed. The algorithm is based on an optimal allocation policy, which is derived in this paper, using the concept of the working set. A brief description of the hardware implementation of the algorithm is also presented. It is shown that under this optimal allocation policy "the value of a page-frame" (the amount of reduction in the page fault rate if an additional page frame is allocated to that program) to each program is the same.

Study of Memory Partitioning for Multiprogramming Systems with Virtual Memory *by M. Z. Ghanem, p. 451.* In this paper, we investigate the effect that the shape of the lifetime function has on the optimal partition of the main memory of a computer among N programs, where the criterion of optimality is maximization of CPU utilization. We used a simple queuing model as a base for understanding this interrelationship. The lifetime function is the average of the execution intervals of a program as a function of the amount of memory allocated. When the lifetime function is convex and is proportional to m^α, where m is the size of memory, then the optimal partition is obtained by dividing the main memory equally among q of the N programs (q is the optimal degree of multiprogramming). Thus, the best partition is always one of two policies; allocate all memory equally among the q programs or allocate all memory to one program. When the lifetime function has a degenerate S shape (is proportional to m^α when $m \leq m_0$ and remains constant beyond m_0), then there exists a memory size m such that no program can have a memory other than m or m_0; if any program has a memory size greater than m_0, each other program should have a memory size that is equal to or greater than m_0.

Introduction to Regenerative Simulation *by S. S. Lavenberg and D. R. Slutz, p. 458.* A recently developed method for estimating confidence intervals when simulating stochastic systems having a regenerative structure is reviewed. The paper is basically tutorial, but also considers the pragmatic issue of the simulation duration required to obtain valid estimates. The method is illustrated in terms of simulating the M/G/1 queue. Analytic results for the M/G/1 queue are used to determine the validity of the simulation results.

Regenerative Simulation of a Queuing Model of an Automated Tape Library *by S. S. Lavenberg and D. R. Slutz, p. 463.* Recently, techniques have been developed for estimating confidence intervals when simulating stochastic systems having a regenerative structure. These techniques are applied to the simulation of a queuing model of a computer system's automated tape library. Theoretical and practical issues related to the application of these techniques are addressed. An interesting feature of the automated tape library represented in the queuing model is that certain queues have finite capacity; when these queues are filled to capacity certain services are prevented from occurring. The regenerative techniques are used in conjunction with multiple comparison procedures to make statistically valid statements about the effect of the finite queue capacities on performance.

Sequential Server Queues for Computer Communication System Analysis *by W. Chang, p. 476.* A queuing model with

two sequential servers is developed to analyze performance in computer and communication systems. In one case the CPU is the first server and the terminal and its associated communications equipment are the second server. In a second case the CPU and the channel are the first server and the auxiliary storage device is the second server. We study the queuing behavior of the sequential server systems with Poisson arrivals, general service time distributions, and several service disciplines, including bulk arrivals, message priorities, and the input and output queues. The stationary distributions of the queue lengths and waiting times are determined by using an imbedded Markov chain analysis. Several examples are given to illustrate the applications of these models to practical problems.

Analysis of a Loop Transmission System with Round-Robin Scheduling of Services *by R. M. Wu and Y.-B. Chen, p. 486.* A finite population, multi-queue model is developed for a loop transmission system. Approximate expressions for the state transition matrix and other system variables are derived in recursive forms. It is also shown that a number of useful system parameters, such as average message response time, average cycle time, and average response time conditioned on message length, can be obtained. The analytical results have been validated by simulation.

Optimal Scheduling Strategies for Real-Time Computers *by U. Herzog, p. 494.* In order to fulfill response time constraints in real-time systems, demands are often handled by means of sophisticated scheduling strategies. This paper first shows how to describe and analyze arbitrary combinations of preemptive and non-preemptive (head-of-the-line) priority strategies and, second, presents an algorithm that yields the optimal priority strategy, taking into consideration constraints on the response time.

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Theory of Liquid Ink Development in Electrophotography *by Y.-O. Tu, p. 514.* When an electric field is present across two different fluid dielectrics having a common plane boundary, some disturbances in the interfacial boundary are found to grow in time. The liquid ink development process is viewed as the result of varying instability of the oil-ink interface as a function of the differing field gradient in light and dark areas of the exposed image. In an analysis of the disturbances into normal modes, the theory relates the effects upon instability due to potential difference across the oil, the surface tension, the respective viscosities of the oil and the ink, and the finite thicknesses of the oil, ink, and the photoconductor layer. The threshold potential difference for the onset of instability is also given.

Multiconic Surfaces *by B. Dimsdale and K. Johnson, p. 523.* Multiconic surfaces are a generalization of the type of surface called polyconic in numerical control of machine tools. The general theory is developed in this paper using a new parametrization. In the original form there was a problem as to whether or not a point that satisfies surface equations actually belonged to the intended surface. This difficulty is removed by the new technique.

Algorithms for calculation of line and plane intersections with the surface and for calculation of normal vectors, volume, and surface area are given for classes of defining functions of which it is required only that they have appropriate conditions of continuity and differentiability.

Examples are given of surfaces developed using spline functions. Preliminary comparative estimates of design and numerical control processing times are included.

Threshold Voltage Characteristics of Double-boron-implanted Enhancement-mode MOSFETs *by P. P. Wang and O. S. Spencer, p. 530.* Threshold voltage characteristics are presented for a double boron-ion-implanted *n*-channel enhancement MOSFET device for high speed logic circuit applications. A 15-Ω-cm high resistivity *p*-type (100) substrate was used to achieve low junction capacitance and low threshold substrate sensitivity. A shallow boron implant was used to raise the threshold voltage, and a second, deeper, boron implant was used to increase the punch-through voltage between the source and the drain. This design is especially beneficial for short channel devices, while maintaining the low junction capacitance and low threshold substrate sensitivity of the high resistivity substrate. A one-dimensional analysis was performed to predict the effects of ion implantation dose and energy on the device characteristics, and a quasi two-dimensional analysis was used to account for the short channel effect. The calculated results agree well with the behavior of experimental devices fabricated in the laboratory.

Computation of Incident Solar Energy *by J. V. Dave, P. Halpern, and H. J. Myers, p. 539.* Computations of the daily and annual totals of the solar energy incident upon south-facing tilted flat surfaces were carried out for several cloudfree atmospheric models after taking into account, somewhat arbitrarily, the contribution due to sky radiation and that due to radiation reflected by the ground. Representative variations of these quantities are discussed as a function of several parameters such as geographical latitude of the location, tilt angle of the surface, atmospheric transmission characteristics, sky-radiation contribution, and ground reflectivity.

Model for Interactive Data Base Reference String *by M. C. Easton, p. 550.* A particularly simple Markov chain model for a reference string is described. The model, which is only slightly more complicated than the independent reference model, generates strings that have a locality property and that have a specified probability distribution of references over pages. Expressions are obtained for expected working-set size and expected working-set miss ratio. The model is used in an examination of the effect of grouping pages into blocks and

in a discussion of the problem of evaluating the effect of changes in the size of the data base. Predictions of the model are shown to agree closely with observations of a string of data base references generated by an interactive data base system having a large number of concurrent users.

HEME: A Self-Improving Computer Program for Diagnosis-Oriented Analysis of Hematologic Diseases *by B. J. Flehinger and R. L. Engle, Jr., p. 557.* HEME, a computer program for diagnosis-oriented analysis of hematologic diseases, accepts as input information about a patient and provides as output an ordered list of suggested diagnoses, an analysis of the logic behind these diagnoses, and a list of tests relevant to these diagnoses and not yet performed. The decision algorithm is based on Bayes' Theorem. Each disease in the system is individually analyzed, and the probability that the patient has the disease vs the probability that he does not is calculated. Bayesian methods of statistical inference are utilized in that the prior probabilities of the diseases and the probabilities of findings in given diseases were initially estimated from the judgment of experienced hematologists with the intention that they be modified automatically as data are accumulated. This program is intended for use in teaching hematology, as an aid to diagnosis, and as a means for studying the diagnostic process.

Modified Nodal Approach to DC Network Sensitivity Computation *by C. W. Ho, p. 565.* Programming techniques are presented for computing dc sensitivity vectors of nonlinear electronic circuits. The modified nodal approach is used as the method of formulation for the circuit equations, in which multiple performance objectives can be accommodated. Numerical examples illustrate some of the techniques discussed.

Mathematical Construct for Program Reorganization *by D. P. Pazel, p. 575.* A mathematical formalism is described through which a program is given a symbolic representation and, with the application of several basic formulas, may be transformed into an equivalent representation giving rise to a reorganized program. Examples are given in which programs are simplified (e.g., code is reduced) or reorganized into a structured form. In effect a mathematics is described that applies to programs in much the same manner as Boolean algebra applies to switching circuits.

On Some Relations between the Laplace and Mellin Transforms *by J. S. Lew, p. 582.* Several earlier papers have applied some identities relating the Laplace and Mellin transforms; this note develops certain such identities, achieving greater generality and rigor. Specifically each of these transforms is expressed as a contour integral involving the other, and an expansion of the Laplace transform is derived in terms of the functions $(s \cdot d/ds)^n(1+s)^{-1}$ with coefficients defined by the Mellin transform.

Amorphous GdCoCr Films for Bubble Domain Applications *by J. Schneider, p. 587.* Amorphous GdCoCr films of various composition ratios made by rf bias sputtering are investigated for their applicability as bubble domain supporting materials. Film compositions around $Gd_{0.13}\,Co_{0.65}\,Cr_{0.22}$ have temperature-insensitive magnetizations between 240 K and 350 K with $T_{comp} \approx 120$ K and $T_c \approx 630$ K. Reduction of the Cr content from 21.8 to 20.3 at. percent causes an increase of the magnetization by a factor of three. Thermal cycling of these films between 290 K and 570 K does not change the magnetization noticeably, nor does annealing for up to six days at 520 K.

The films are found to be very susceptible to contamination by the residual oxygen present in the vacuum chamber during sputtering. Films contaminated with 3 to 13 at. percent oxygen have coercivities around 800 A/m (10 Oe), whereas films which were oxygen-free according to microprobe investigations show coercivities less than 80 A/m (1 Oe).

Effect of Submicrometer Transducer Spacing on the Readback Signal in Saturation Recording *by F. E. Talke and R. C. Tseng, p. 591.* Experimental results for frequency response and halfpulse width of digital recording signals have been obtained for submicrometer transducer spacings, for the case of a flexible disk flying in close proximity to a rigidly mounted conventional ferrite recording head. Using optical flying heights rather than an "effective spacing," together with a modification of the Williams-Comstock write-process slope criterion, we have obtained excellent agreement between experimental results and theoretical predictions. This suggests that the notion of effective spacing can be avoided.

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Preface *by R. Ashany, p. 2.*

Computers and the Space Program: An Overview *by C. C. Kraft, Jr., p. 3.*

Development of On-board Space Computer Systems *by A. E. Cooper and W. T. Chow, p. 5.* This paper describes the functions, characteristics, requirements, and design approaches of the on-board computers for seven space vehicles—Saturn I, Orbiting Astronomical Observatory, Gemini, Saturn IB, Saturn V, Skylab, and Space Shuttle. The data contained in this paper represent an encapsulation of sixteen years of space-borne-computer development. In addition, the evolution of computer characteristics such as size, weight, power consumption, computing speed, memory capacity, technology, architectural features, software, and fault-tolerant capabilities, is summarized and analyzed to point out the design trends and the motivating causes. The evolution in utilization of the on-board computers; their interface with sensors, displays, and controls; and their interaction with operators are summarized and analyzed to show the increasing role played by computers in the overall space-vehicle system.

Redundancy Management Technique for Space Shuttle Computers *by J. R. Sklaroff, p. 20.* This paper describes how a set of off-the-shelf general purpose digital computers is being managed in a redundant avionic configuration while performing flight-critical functions for the Space Shuttle. The description covers the architecture of the redundant computer set, associated redundancy design requirements, and the technique used to detect a failed computer and to identify this failure on-board to the crew. Significant redundancy management requirements consist of imposing a total failure coverage on all flight-critical functions, when more than two redundant computers are operating in flight, and a maximum failure coverage for limited storage and processing time, when only two are operating. The basic design technique consists of using dedicated redundancy management hardware and software to allow each computer to judge the "health" of the others by comparing computer outputs and to "vote" on the judgments. In formulating the design, hardware simplicity, operational flexibility, and minimum computer resource utilization were used as criteria.

Performance Modeling of Earth Resources Remote Sensors *by R. H. Kidd and R. H. Wolfe, p. 29.* A technique is presented for constructing a mathematical model of an Earth resources remote sensor. The technique combines established models of electronic and optical components with formulated models of scan and vibration effects, and it includes a model of the radiation effects of the Earth's atmosphere. The resulting composite model is useful for predicting in-flight sensor performance, and a descriptive set of performance parameters is derived in terms of the model. A method is outlined for validating the model for each sensor of interest. The validation for one airborne infrared scanning system is accomplished in part by a satisfactory comparison of predicted response with laboratory data for that sensor.

Digital Image Processing of Earth Observation Sensor Data *by R. Bernstein, p. 40.* This paper describes digital image processing techniques that were developed to precisely correct Landsat multispectral Earth observation data and gives illustrations of the results achieved, e.g., geometric corrections with an error of less than one picture element, a relative error of one-fourth picture element, and no radiometric error effect. Techniques for enhancing the sensor data, digitally mosaicking multiple scenes, and extracting information are also illustrated.

Skylab Attitude Control System *by T. R. Coon and J. E. Irby, p. 58.* The attitude stabilization and control system for Skylab evolved from an analog controller into a fully digital processing system. Features of this system include a software-determined attitude reference to provide general maneuvering ability, an in-orbit programming capability, the use of large control moment gyros for attitude control, and the use of vehicle maneuvers to desaturate gyro momentum. The objectives, requirements, and implementations of the control system software are described, along with the rationales for certain design decisions and discussion of some system dynamics and actual performance.

Large Space Telescope *by F. J. Hudson, p. 67.* The Large Space Telescope, which is scheduled to be put into orbit above the Earth's atmosphere by NASA in the early 1980s, is a large, multipurpose optical instrument that is being designed to provide an increase in observational capability of nearly 100× with respect to brightness, 10× in resolving power, and a substantial bandwidth improvement over ground-based facilities. This paper describes, from a functional performance viewpoint, the LST system and, in greater detail, the on-board Data Management and Pointing Control Systems.

Launch Processing System *by F. Byrne, G. V. Doolittle, and R. W. Hockenberger, p. 75.* This paper presents a functional description of the Launch Processing System, which provides automatic ground checkout and control of the Space Shuttle launch site and airborne systems, with emphasis placed on the Checkout, Control, and Monitor Subsystem. Hardware and software modular design concepts for the distributed computer system are reviewed relative to performing system tests, launch operations control, and status monitoring during ground operations. The communication network design, which uses a Common Data Buffer interface to all computers to allow computer-to-computer communication, is discussed in detail.

Real-Time Orbiter Abort Guidance *by V. S. Sohoni, p. 84.* This paper describes a real-time abort guidance algorithm which determines the time sequence of the powered maneuvers and the orientation of the thrust vector throughout

an abort-mission action initiated during the orbiter ascent phase. It involves guiding a heavily loaded Space Shuttle vehicle, passing through severe environmental conditions, back to a designated landing area. A graphical example and estimates of the computer requirements are included.

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Submicrometer Stripes and Bubbles in Amorphous Films *by P. Chaudhari and S. R. Herd, p. 102.* Lorentz microscopy is used to study amorphous thin films of Gd-Co-Au and Gd-Co-Mo having a range of Q values. Stripe and bubble formation are shown as a function of perpendicular bias fields and pulsed or rotating in-plane fields. In the presence of an in-plane field, stripes contain a pair of Bloch lines and break into rows of Bloch-line containing bubbles. A unichiral stripe, however, forms a unichiral bubble that is stable to higher perpendicular bias fields than are Bloch-line bubbles. Bloch-line rotation in bubble walls in the presence of external rotating fields is demonstrated, and Bloch-line motion due to sweeping in-plane walls is shown. The rare occurrence of four Bloch lines in a 0.2-μm bubble is observed, as is the pearl-like accumulation of multiple Bloch lines in walls of irregularly shaped domains.

Bubble Lattice Motions Due to Modulated Bias Fields *by B. E. Argyle, J. C. Slonczewski, and O. Voegeli, p. 109.* We observe that periodic variations of bias field can couple to a close-packed lattice of magnetic bubbles to produce a steady rotation of the bubble lattice (RBL). Pulsed fields excite various other many-body phases as well. The physical motions of such bubble arrays can be described by "lattice melting," "evaporation," and "rotating galaxies." The RBL phase is stable over wide ranges of pulse width and amplitude when the film is thick and the lattice is confined either by a circular ion-milled groove or by radially symmetric inhomogeneous fields from the excitation coil itself. Microsecond pulsed fields of $-0.05 \times 4\pi M_s$ applied to a lattice of five-μm bubbles produce a net displacement of up to 1.5 μm/pulse at the rim of a lattice 23 bubbles across and 250 μm in diameter. Sinusoidal bias modulation in the range 1 to 30 MHz produces a spectrum of lattice rotational velocities vs frequency having both signs. At frequencies near the low end of the spectrum both the magnitude and the sign of the rotation are sensitive to drive amplitude. A tentative theory attributes lattice rotation to nonlinearities involving the bubble-deflection effect. The mechanism is strong enough to account for the observed magnitude of rotational frequency and can explain its resonant peaks and sign changes.

Storage Management Operations in Linked Uniform Shift-Register Loops *by T.-C. Chen and C. Tung, p. 123.* A new storage structure, called a uniform ladder, consists of a linear array of equal shift-register loops, each holding one record and linked by flow-steering switches. Data exchange across a loop boundary is mandatory if the controlling switch is on and forbidden if off. For MRU (Most Recently Used) storage management, the most important operation is the climbing of data to the top of the ladder from a depth of D loops, which takes only $(D + 1)/2$ record periods in the uniform ladder. Program switching is enhanced by efficient schemes for partial environmental exchanges and also by internal block transfers. A pushdown stack can be efficiently implemented by a change in the record storing technique.

Effects of Abrupt Changes in Film Thickness on Magnetic Bubble Forces *by T. W. Collins and R. W. Cole, p. 132.* Forces on a magnetic bubble due to abrupt asymmetric changes in the surface configuration of the magnetic film are investigated theoretically and experimentally. A model is derived for calculating the forces on a bubble as it is being moved by conductor propagation through a thickness gradient in the film. An experiment is described in which the forces necessary to move a bubble through this transition region are measured and compared with predicted values computed from the model. Results are presented for a 20° gradient with a cut 0.62 μm deep in a garnet film, nominally 3.8 μm thick, prepared by liquid phase epitaxy.

Bases for Chain-complete Posets *by G. Markowsky and B. K. Rosen, p. 138.* Various authors (especially Scott, Egli, and Constable) have introduced concepts of "basis" for various classes of partially ordered sets (posets). This paper studies a basis concept directly analogous to the concept of a basis for a vector space. The new basis concept includes that of Egli and Constable as a special case, and one of their theorems is a corollary of our results. This paper also summarizes some previously reported but little known results of wide utility. For example, if every linearly ordered subset (chain) in a poset has a least upper bound (supremum), so does every directed subset.

Given posets P and Q, it is often useful to construct maps $g{:}P \to Q$ that are *chain-continuous:* supremums of nonempty chains are preserved. Chain-continuity is analogous to topological continuity and is generally much more difficult to verify than *isotonicity:* the preservation of the order relation. This paper introduces the concept of an *extension basis:* a subset B of P such that any isotone $f{:}B \to Q$ has a unique chain-continuous extension $g{:}P \to Q$. Two characterizations of the chain-complete posets that have extension bases are obtained. These results are then applied to the problem of constructing an extension basis for the poset $[P \to Q]$ of chain-continuous maps from P to Q, given extension bases for P and Q. This is not always possible, but it becomes possible when a mild (and independently motivated) restriction is imposed on either P or Q. A lattice structure is not needed.

Drop Formation from a Liquid Jet: A Linear One-dimensional Analysis Considered as a Boundary Value Problem *by W. T. Pimbley, p. 148.* Using a one-dimensional model, the author studied drop formation using a boundary value perturbation, rather than a spatially periodic one as considered by Rayleigh. The Rayleigh

solution becomes the high jet velocity approximation to this linear analysis. At lower velocities the analysis shows that the medium becomes dispersive, and drop formation characteristics are quite different from that predicted by Rayleigh. In an appendix, the gross momentum balance and flow rate conservation are used to consider drop formation from a stream.

Objects and Values: The Basis of a Storage Model for Procedural Languages *by D. B. Lomet, p. 157.* A model for storage in procedural languages is presented. Its fundamental notion is to strictly distinguish values from storage objects. Several difficulties in current languages are resolved in this model, e. g., the problem of flexible locations and the meaning of the term type. In the light of the storage object/value dichotomy, several notions are found to be covered by the term type. The implications of the model are explored with respect to the more conventional data constructs of procedural languages as well as to sets and how they might be provided. Finally, data extension mechanisms are considered. Whereas the treatment here is not complete, the template concept introduced in the model does suggest a useful framework for providing the much talked of but seldom realized benefits of data extensibility.

Error Correcting Codes for Satellite Communication Channels *by C.-L. Chen and R. A. Rutledge, p. 168.* This paper addresses the problem of efficient forward error correction on differentially encoded, quadriphase-shift-keying (DQPSK) channels. The approach is to design codes to correct the most probable error patterns. First the probability distribution of error patterns is derived. Then a class of convolutional codes that correct any single two-bit error is described. Finally a threshold decodable code that corrects all single, and many double, two-bit errors is presented.

Electric Motor Requirements for Positioning an Inertial Load *by J. H. Meier and J. W. Raider, p. 176.* This paper deals with the motor, the inertia ratio, and the power input requirements for moving an inertial load over a specified distance in a specified time. A linear speed-torque relationship is assumed, and selected motor parameters are normalized to the load to establish generally applicable solutions and characteristic curves. Emphasis is placed on the velocity-time diagrams and the relationship among the inertia ratio, the rated motor power, and the electrical input power. It is shown that optimization is possible for input power at stall, input power immediately following torque reversal, and average input power. Computer generated curves are presented for these three cases, and their relationships are discussed. Finally, it is shown that the motor time constant has a great influence on power requirements.

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Generalized Kraft Inequality and Arithmetic Coding *by J. J. Rissanen, p. 198.* Algorithms for encoding and decoding finite strings over a finite alphabet are described. The coding operations are arithmetic involving rational numbers l_i as parameters such that $\Sigma_i 2^{-l_i} \leq 2^{-\epsilon}$. This coding technique requires no

blocking, and the per-symbol length of the encoded string approaches the associated entropy within ϵ. The coding speed is comparable to that of conventional coding methods.

Analysis of the Berlekamp-Massey Linear Feedback Shift-Register Synthesis Algorithm *by F. G. Gustavson, p. 204.* An analysis of the Berlekamp-Massey Linear Feedback Shift-Register (LFSR) Synthesis Algorithm is provided which shows that an input string of length n requires $O(n^2)$ multiplication/addition operations in the underlying field of definition. We also derive the length distribution for digit strings of length n. Results show that, on the average, the encoded length is no greater than $n + 1$. Furthermore, we exhibit a connection between step 1 of the Ling-Palermo algorithm and the LFSR Algorithm, and the LFSR Algorithm turns out to be computationally superior.

Deep-UV Conformable-Contact Photolithography for Bubble Circuits *by B. J. Lin, p. 213.* The techniques of deep-ultraviolet (UV) conformable-contact photolithography are described and some preliminary work reported on their application to the fabrication of high-density bubble memory circuits by single-level masking. A quantitative analysis of tolerance requirements for linewidth, mask-to-wafer gap, and exposure is made for printing with conventional UV and deep-UV, for feature sizes in the range 2.5 μm to 0.1 μm. A new type of mask-to-wafer holder is described, utilizing a diaphragm to achieve contact. The holder can be used for either a conformable wafer or a conformable mask, or for both conformable wafer and mask, and for the liquid gap technique. Developmental bubble memory circuits on amorphous and garnet materials have been fabricated using deep-UV conformable-contact photolithography, electroplating, liftoff, and ion milling.

Lattice Dynamics with Three-Body Forces: Solid Xe and Kr *by J. A. Barker, M. L. Klein, and M. V. Bobetic, p. 222.* Phonon dispersion curves, elastic constants, and the pV isotherms are calculated for solid Xe and Kr at 0 K using quasiharmonic lattice dynamics derived from multiparameter pair potentials. The computations account for the Axilrod-Teller-Muto three-body triple-dipole forces that arise in third-order perturbation theory. Approximate allowance is also made for anharmonic effects and, in the case of Xe, for three-body, third-order, dipole-quadrupole interactions and the three-body dipole interactions that arise in fourth-order perturbation theory. The over-all agreement with experimental phonon data is good except, in the case of xenon, for the lowest-energy phonons in the <110> direction. This has the consequence that the shear elastic constant $(C_{11} - C_{12})/2$ and the zero temperature Debye theta are somewhat lower than current experimental values.

LSI Yield Modeling and Process Monitoring *by C. H. Stapper, p. 228.* This paper describes an analytical technique for quantifying and modeling the frequency of occurrence of integrated circuit failures. The method is based on the analysis of random and clustered defects on wafers with defect monitors. Results from pilot line data of photolithographic defects, insulator short circuits, and leaky pn junctions are presented to support the practicality of the approach. It is shown that, although part of the yield losses are due to the clustering of defects, most product loss is from random failures. The yield model shows good agreement with actual product yields.

Delayed Closed-Loop Scheme for Stepping Motor Control *by B. Bechtle, C. Schünemann, G. Skudelny, and V. Zimmermann, p. 235.* An efficient method for control of stepping motor speed and position, the delayed closed-loop (DCL) mode, is described. The new technique permits control of high-speed motor motion by means of a programmed speed-displacement characteristic. The method combines the static-speed control characteristic of the open-loop mode with the stable dynamic behavior of the closed-loop mode. Unlike other schemes for delayed closed-loop control, the present configuration features an extension of delay time to more than one step duration, significantly improving the velocity control. The phase angle can also be varied to ±180°, permitting adequate control of deceleration as well as acceleration. A stability analysis is made of the DCL control method. In an illustrative example, the technique is applied to control of the carriage drive on an experimental high-speed line printer.

Optimization of Single Expressions in a Relational Data Base System *by P. A. V. Hall, p. 244.* This paper examines optimization within a relational data base system. It considers the optimization of a single query defined by an expression of the relational algebra. The expression is transformed into an equivalent expression or sequence of expressions that cost less to evaluate. Alternative transformations, and combinations of several transformations, are analyzed. Measurements on an experimental data base showed improvements, especially in cases where the original expression would be impracticably slow in its execution. A small overhead was incurred, which would be negligible for large data bases.

Dependence of Ink Jet Dynamics on Fluid Characteristics *by C. A. Bruce, p. 258.* Measurements of jet velocity, separation length, and stream stability (freedom from random fluctuations in drop position) were made for several fluids, including two inks. The data were then compared with modified fluid flow and jet stability equations. In one case velocity is related to applied pressure drop through a flow equation that depends primarily on the shape and size of the nozzle and on fluid viscosity. In the other case Weber's equation is modified to include forced oscillation, so that separation length is related to the voltage applied to a piezoelectric crystal, to disturbance growth rate, and to velocity. These two equations were applicable to "normal" liquids (those having good stream stability) having viscosities between 0.9 and 4.3 grams/(second · meter) and dynamic surface tensions between 20 and 60 grams/s^2, but not to dilute solutions of a high molecular weight polymer, owing to their viscoelastic character. Furthermore, the stream stability of the polymer solutions was poor and depended inversely on concentration and molecular weight.

Amorphous Materials for Micrometer and Submicrometer Bubble Domain Technology *by C. H. Bajorek and R. J. Kobliska, p. 271.* A review and critique is made of those material and processing issues that pertain to the implementation of micrometer and submicrometer bubble devices on amorphous films. Adequate reproducibility and uniformity have been achieved in ternary amorphous films prepared by rf sputtering and their magnetic characteristics are very similar to those of analogous garnet films. Factors that may limit application to the amorphous films include defects and dielectric breakdown in insulating layers, sensitivity to annealing, and larger, but not prohibitive, coercivities. A salient problem common to both garnet and amorphous materials is attainment of sufficiently large values of Q to ensure stable device operation.

Complex Convolutions via Fermat Number Transforms *by H. J. Nussbaumer, p. 282.* An approach is described for computing complex convolutions modulo a Fermat number. It is shown that this technique is particularly efficient when the complex convolution is computed by means of Fermat Number Transforms and leads to improved implementation of complex digital filters.

Speckle Pattern Interferometry of Vibration Modes *by I. M. Andrews and J. A. Leendertz, p. 285.* An optical facility is described for the study of the vibrational behavior of engineering test pieces. Time-average holography and electronic speckle pattern methods of analysis are combined into one system. The speckle pattern method is used for the identification of resonances, frequency tuning, and object alignment, thereby optimizing the number of holographic exposures. An evaluation is made of the electronic speckle pattern method for the detection of vibration modes of three-dimensional objects. The method is shown to detect resonant vibration readily on object faces inclined at angles up to 60° to the viewing direction.

Comment on "Segment Synthesis in Logical Data Base Design" *by G. Wiederhold, p. 290.*

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Automatic Programming Through Natural Language Dialogue: A Survey *by G. E. Heidorn, p. 302.* This paper describes and compares four research projects whose goal is to develop an automatic programming system that can carry on a natural language dialogue with a user about his

requirements and then produce an appropriate program. It also discusses some of the important issues in this research area.

On Natural Language Based Computer Systems *by S. R. Petrick, p. 314.* Some of the arguments that have been given both for and against the use of natural languages in question-answering and programming systems are discussed. Several natural language based computer systems are considered in assessing the current level of system development. Finally, certain pervasive difficulties that have arisen in developing natural language based systems are identified, and the approach taken to overcome them in the REQUEST (Restricted English QUESTion-Answering) System is described.

REQUEST: A Natural Language Question-Answering System *by W. J. Plath, p. 326.* REQUEST is an experimental Restricted English QUESTion-answering system that can analyze and answer a variety of English questions, spanning a significant range of syntactic complexity, with respect to a small *Fortune*-500-type data base. The long-range objective of this work is to explore the possibility of providing nonprogrammers with a convenient and powerful means of accessing information in formatted data bases without having to learn a formal query language. To address the somewhat conflicting requirements of understandability for the machine and maximum naturalness for the user, REQUEST uses a language processing approach featuring: 1) the use of restricted English; 2) a two-phase, complier-like organization; and 3) linguistic analysis based on a transformational grammar. The present paper explores the motivation for this approach in some detail and also describes the organization, operation, and current status of the system.

Conceptual Graphs for a Data Base Interface *by J. F. Sowa, p. 336.* A data base system that supports natural language queries is not really natural if it requires the user to know how the data are represented. This paper defines a formalism, called conceptual graphs, that can describe data according to the user's view and access data according to the system's view. In addition, the graphs can represent functional dependencies in the data base and support inferences and computations that are not explicit in the initial query.

Bicubic Patch Surfaces for High-Speed Numerical Control Processing *by B. Dimsdale and R. M. Burkley, p. 358.* Parametric bicubic patch surfaces have been used for some time in manufacture and design. It is convenient to have such surfaces available as standard numerical control surfaces using the APT programming language. A major drawback is that they are costly to use for data processing of numerical control programs. If, however, nonparametric bicubics are used, computer time, and hence cost, can be reduced dramatically. This paper details a strategy and algorithms for this purpose. Experimental data suggest that computer costs are comparable to, or somewhat lower than, the costs for processing tabulated cylinder surfaces.

Column Access of a Bubble Lattice: Column Translation and Lattice Translation *by B. A. Calhoun, J. S. Eggenberger, L. L. Rosier, and L. F. Shew, p. 368.* The use of a regular array, or lattice, of magnetic bubbles for the storage of information requires two kinds of functions: the read-write functions involving the generation and discrimination of bubbles with different wall structures, and the access functions involving the insertion and removal of bubbles at selected locations in the lattice. In a column-accessed bubble lattice device, accessing is accomplished by first translating the lattice to position the desired column of bubbles in an input-output access channel and then translating this column along the channel to a detector area outside of the lattice while simultaneously introducing new bubbles from a generator area at the other end of the channel. An analysis of the influence of device design parameters on access rate indicates that the most important parameters are the column translation rate and lattice capacity. A device is described that was designed to study the translation of a lattice of bubbles and of a single column of bubbles within the lattice. Quasistatic operating margins and dynamic measurements of this test device indicate that the column-access configuration provides feasible means for the rapid access of bubbles from a lattice.

Scanning Electron Beam Lithography for Fabrication of Magnetic Bubble Circuits *by T. H. P. Chang, M. Hatzakis, A. D. Wilson, A. J. Speth, A. Kern, and H. Luhn, p. 376* A high-resolution technique is described for the experimental fabrication of Permalloy patterns for magnetic bubble circuits having linewidths as small as 3000 Å. The system includes a computer-controlled electron beam, automatic registration, a modified field-stitching method, and exposure control to compensate for proximity effects. Patterns are formed either by electroplating or by evaporation. The system can be used either for directly writing on bubble wafers or for fabricating masks for x-ray or conformable-mask printing.

Design of a Swinging Arm Actuator for a Disk File *by J. S. Heath, p. 389.* An integral disk enclosure that incorporates a novel head-positioning actuator concept is used in the IBM System/32 and in recently announced terminal controllers, such as the Retail Store Controller and the Communication Controller. Based on a swinging arm rather than the conventional linear carriage, the actuator presented the designers with opportunities to create a simplified mechanism and to gain advantages in reliability and cost. This paper describes the geometrical, structural, and electromechanical basis of the design.

Fast Beamforming with Circular Receiving Arrays *by H. P. Raabe, p. 398.* The Fast Fourier Transform (FFT) can be applied to circular arrays receiving wideband sonar radiation. As with conventional beamforming, the FFT serves in the first stage to divide the spectrum into narrow frequency bands.

Then the array element responses of each band are analyzed in a second stage of FFTs for the Fourier components (modes) of the array excitation function for the respective band. Application of weights of the mode responses, to simulate the radiation efficiency of the modes for any given element radiation pattern and to control the array pattern, yields the Fourier components of the beam pattern. To integrate these Fourier components, inverse FFTs follow which yield as many beam pattern samples as there are array elements.

Structure and Magnetic Anisotropy of Amorphous Gd-Co Films *by A. Onton, N. Heiman, J. C. Suits, and W. Parrish, p. 409.* It is found that the structure of amorphous Gd-Co films, as revealed by x-ray diffraction, is correlated with the magnitude of bias voltage present during the sputter deposition. Films sputter deposited with zero bias voltage typically show one broad peak in an x-ray diffraction spectrum, and films sputter deposited with −100 volts bias show two broad peaks with a shoulder between them. These structural differences appear to be related to the perpendicular magnetic anisotropy in these films.

Comment on "Segment Synthesis in Logical Data Base Design" *by P. A. Bernstein, p. 412.*

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Cubic Splines with Infinite Derivatives at Some Knots *by A. Inselberg, p. 430.* A generalization of cubic spline interpolation with vertical slopes at some knots is proposed. An existence theorem including an algorithm for constructing such generalized splines is proved. The resulting splines are obtained in closed form and they are partition invariant.

Stochastic Modeling of Processor Scheduling with Application to Data Base Management Systems *by S. S. Lavenberg and G. S. Shedler, p. 437.* This paper is concerned with the stochastic modeling of processor scheduling and of queuing due to contention for resources in data base management systems. The processing services rendered in searching the data base and retrieving and processing information are modeled explicitly, as is the algorithm used to schedule these services on the processor. The scheduling of the processor is based on a total priority ordering of a set of queues for processing service. A queuing model incorporating the processor scheduling algorithm for IMS (Information Management System) is formulated in order to illustrate the modeling ideas. The model is analyzed under rather general distributional assumptions, based on the observation that certain stochastic processes in the model are cumulative processes defined over the same embedded semi-Markov process. The model is not used in a performance study of IMS, nor is it proposed that the model developed here is one upon which a performance study of IMS should be undertaken. The model should be viewed as illustrative of stochastic models which can be constructed to incorporate algorithms for processor scheduling.

Exploratory Analysis of Access Path Length Data for a Data Base Management System *by D. P. Gaver, S. S. Lavenberg, and T. G. Price, Jr., p. 449.* An exploratory approach is taken to analyze a vast quantity of data recorded during the running of the data base management system IMS (Information Management System). The collection of data analyzed is a sequence of access path lengths for a day-long period. The number of segments accessed by IMS when searching a data base in order to retrieve a specified segment for a user is called an access path length. Part of the motivation for the analysis is to suggest reasonable stochastic models for the access path length sequence that can be conveniently utilized as input models for a stimulation model of an IMS installation. The exploratory approach taken to the data involves the use of graphical displays and simple numerical summaries to reveal characteristics of, and patterns in, the data. Some simple ways are presented in which the structure of the data revealed by the analysis can be incorporated into an input model for a system simulation.

Statistical Analysis of Non-stationary Series of Events in a Data Base System *by P. A. W. Lewis and G. S. Shedler, p. 465.* Central problems in the performance evaluation of computer systems are the description of the behavior of the system and characterization of the workload. One approach to these problems comprises the interactive combination of data-analytic procedures with probability modeling. This paper describes methods, both old and new, for the statistical analysis of non-stationary univariate stochastic point processes and sequences of positive random variables. Such processes are frequently encountered in computer systems. As an illustration of the methodology an analysis is given of the stochastic point process of transactions initiated in a running data base system. On the basis of the statistical analysis, a non-homogeneous Poisson process model for the transaction initiation process is postulated for periods of high system activity and found to be an adequate characterization of the data. For periods of lower system activity, the transaction initiation process has a complex structure, with more clustering evident. Overall models of this type have application to the validation of proposed data base subsystem models.

A General Methodology for Data Conversion and Restructuring *by V. Y. Lum, N. C. Shu, and B. C. Housel, p. 483.* This paper presents a methodology and a model for data conversion or translation. The model assumes that both source and target systems are available and that conversion interfaces may be required to interact between these systems and the conversion system. To achieve data conversion or translation using this approach, two languages are needed: 1) a language to describe the data structures, and 2) a language to specify the mapping between source and target data. This paper describes these two languages, DEFINE and CONVERT and gives numerous examples to show the capabilities of these languages and how they can be used in

data conversion and restructuring. Both languages are high level and nonprocedural and have the power to deal with most situations encountered in data conversion processes. In addition, the paper also describes some of the facilities in the languages specifically designed for data checking in a data conversion process.

Digital Filtering Using Complex Mersenne Transforms *by H. J. Nussbaumer, p. 498.* Complex Mersenne Transforms are defined in a ring of integers modulo a Mersenne or pseudo-Mersenne number and can be computed without multiplications. It is shown that under certain conditions, these transforms can be computed by means of fast transform algorithms and permit the evaluation of digital convolutions with better efficiency and accuracy than does the Fast Fourier Transform.

Derivation of Miss Ratios for Merged Access Streams *by G. S. Shedler and D. R. Slutz, p. 505.* An access stream is the sequence of storage accesses made by an executing program; a merged stream results from the multi-programming of a number of individual access streams. Assuming that LRU (least recently used) miss ratio functions for individual streams are known, we consider the problem of predicting the LRU miss ratio function for merged streams. Each access stream is modeled as a sequence of independent, identically distributed LRU stack distances which evolves in time as a Poisson process and the merged stream is taken to be the superposition of these processes. For an arbitrary number of such streams, a closed form expression for the expected miss ratio function is obtained.

An Analysis of Buffer Paging in Virtual Storage Systems *by W. G. Tuel, Jr., p. 518.* Storage buffers are often used to hold temporary results or data that may be re-referenced in the near future. If these buffers are pagable, searching the buffer may cause a high number of page exceptions. A model of this phenomenon is postulated, and compared with experimental data.

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Walsh Functions for Digital Impedance Relaying of Power Lines *by J. W. Horton, p. 530.* Impedance distance relaying for fault-protection of a plurality of high-voltage lines has not been accomplished with a minicomputer because of the burden of time placed upon these computers. A new method for computing impedance from data samples is proposed, which would employ only the computer operations of Add, Subtract, and Shift. This is valuable because these operations are one to two orders of magnitude faster on present day minicomputers than the operations of Multiply, Divide, Square, and Square Root. The new method is based upon the use of Walsh functions. When compared with the best competitive method, this new method shows superiority in speed and an accuracy that meets proposed objectives.

Buffer Overflow in a Store-and-Forward Network Node *by P. J. Schweitzer and S. S. Lam, p. 542.* Equilibrium behavior of a store-and-forward network node with finite buffer capacity is studied via a network-of-queues model. The positive acknowledgment protocol is explicitly modeled and consumes part of the buffer pool. The principal results are the buffer overflow probability, the mean delays, and the distribution of queue lengths as functions of the buffer capacity and traffic levels.

Scheduling as a Graph Transformation *by E. B. Fernández and T. Lang, p. 551.* The scheduling of a set of tasks, with precedence constraints and known execution times, into a set of identical processors is considered. Optimal scheduling of these tasks implies utilizing a minimum number of processors to satisfy a deadline, or finishing in minimal time using a fixed number of processors. This process can be seen as a transformation of the original graph into another graph, whose precedences do not violate the optimality constraints and has a unique basic schedule. Analysis of this transformation provides insight into the scheduling process and also into the determination of lower bounds on the number of processors and on time for optimal schedules.

SEQUEL 2: A Unified Approach to Data Definition, Manipulation, and Control *by D. D. Chamberlin, M. M. Astrahan, K. P. Eswaran, P. P. Griffiths, R. A. Lorie, J. W. Mehl, P. Reisner, and B. W. Wade, p. 560.* SEQUEL 2 is a relational data language that provides a consistent, English keyword-oriented set of facilities for query, data definition, data manipulation, and data control. SEQUEL 2 may be used either as a stand-alone interface for nonspecialists in data processing or as a data sublanguage embedded in a host programming language for use by application programmers and data base administrators. This paper describes SEQUEL 2 and the means by which it is coupled to a host language.

Data Organization in Magnetic Bubble Lattice Files *by C.-K. Wong and P. C. Yue, p. 576.* In this paper, we discuss several aspects of data organization in the framework of a recently developed magnetic bubble memory technology known as a bubble lattice file. A dynamic ordering scheme, different from those implemented in conventional T-I bar bubble memories, is proposed. This ordering is particularly suited for bubble lattices. Some performance figures are included for comparison.

Procedural Representation of Three-dimensional Objects *by D. D. Grossman, p. 582.* A system of PL/I procedures has been written that permits geometric objects to be described hierarchically. The objects are themselves represented as PL/I procedures, allowing very general use of variables. By effectively intercepting subprogram calls, the system provides a means of modifying the semantics associated with any object without modifying the object's procedural description.

Determining the Three-dimensional Convex Hull of a Polyhedron *by A. Appel and P. M. Will, p. 590.* A method is presented for determining the three-dimensional convex hull of a real object that is approximated in computer storage by a polyhedron. Essentially, this technique tests all point pairs of the polyhedron for convex edges of the convex hull and then assembles the edges into the polygonal boundaries of each of the faces of the convex hull. Various techniques for optimizing this process are discussed. A computer program has been written, and typical output shapes are illustrated. Finding the three-dimensional convex hull is approximately the same computer burden as eliminating hidden lines.

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Application of Ink Jet Technology to a Word Processing Output Printer *by W. L. Buehner, J. D. Hill, T. H. Williams, and J. W. Woods, p. 2.* This paper describes a word processing system output printer that uses the electrostatic synchronous ink jet printing process. An overview of the ink jet matrix printing process is included, as well as brief descriptions of the elements of the printer. Printer performance objectives are outlined, and some of the design problems encountered during development are discussed.

Scale Model of an Ink Jet *by S. A. Curry and H. Portig, p. 10.* A scale model, approximately fifty times the size of its prototype, was used to study drop formation of an ink jet. Viscosity, surface tension, and inertial forces were modeled; gravity and air drag forces were not. The model accurately predicted operating conditions leading to the formation of undesirable satellite drops, thus permitting evaluation of measures designed to avoid them.

Satellite Droplet Formation in a Liquid Jet *by W. T. Pimbley and H. C. Lee, p. 21.* The formation and behavior of satellite droplets in a liquid jet is investigated experimentally and theoretically. The satellite droplet break-off distance is measured stroboscopically as a function of the frequency and amplitude of nozzle vibration. A second-order analysis of spatial instability is developed, which demonstrates the essential features of satellite formation as it is observed. Satellite formation is least likely to occur when the main-drop spacing is five to seven times the jet diameter.

Effect of Parameter Variations on Drop Placement in an Electrostatic Ink Jet Printer *by T. G. Twardeck, p. 31.* This paper discusses the sensitivity of drop-to-drop spacing in the print plane of an ink jet printer to other printer variables. Two designed experiments, a fractional factorial and a central composite, combined with standard analysis identified the critical variables and provided a mathematical expression useful for setting tolerances.

Drop Charging and Deflection in an Electrostatic Ink Jet Printer *by G. L. Fillmore, W. L. Buehner, and D. L. West, p. 37.* This paper describes the drop charging and drop deflection processes in an electrostatic ink jet printer. Included in the discussion of drop charging are induction interaction effects and charge synchronization requirements, as well as design considerations for the charge electrode. In describing the parameters governing drop deflection, some drop placement errors are related to undesired interactions resulting from aerodynamic forces and electrostatic repulsion effects on the drops. A scheme for obtaining accurate drop placement in the presence of these interaction effects is described.

Boundary Layer Around a Liquid Jet *by H. C. Lee, p. 48.* The phenomenon of air wake caused by a train of liquid drops is studied in this paper by approximating the train to a cylindrical jet emerging from a nozzle. The boundary layer equations are derived by applying continuity of jet mass and matching the loss of jet momentum with the air drag on the jet. These equations are solved numerically and compared with experiments in which the velocity change of the jet along the stream is carefully measured through measurements of drop distances. Good agreement is obtained between experimental results and the analysis.

Controlling Print Height in an Ink Jet Printer *by J. M. Carmichael, p. 52.* This paper describes a control system for maintaining constant print height in an ink jet printer. Following power on and during a periodic off-line correction operation a specially designed sensor detects the position of a test group of electrostatically charged ink drops to obtain print height correction data. Information provided by the same sensor is used to synchronize the application of a unique charge to each drop to be printed.

Study of Fluid Flow through Scaled-up Ink Jet Nozzles *by M. Levanoni, p. 56.* A 100-fold scaled-up model of ink jet nozzle flow is described. A theoretical justification for scaling the relevant parameters, starting from the equations of motion, is presented. The scaling procedure and the effects of unscaled parameters are discussed as well as the scaled-up "ink." Following a description of the experimental apparatus, the results of a series of experiments are then presented. These consist of directionality, directional stability and flow efficiency measurements in four nozzle configurations: conical, cylindrical, square, and "hybrid" nozzles.

Development and Characterization of Ink for an Electrostatic Ink Jet Printer *by C. T. Ashley, K. E. Edds, and D. L. Elbert, p. 69.* This paper reviews the development of the ink for an electrostatic ink jet printer. It discusses the formulation logic, test procedures, failure analyses, and problem resolutions. The variables that influence the jet printing process and print quality are defined, and their relationship to specific formulations is discussed. Also considered are the relationships between formulation variables and failure modes inherent in the ink.

Materials Selection for an Ink Jet Printer *by B. L. Beach, C. W. Hildenbrandt, and W. H. Reed, p. 75.* An ink jet printer includes a system of parts that supplies, filters, pumps, circulates, and pulses a jet of ink. These parts, made of various materials (metals, plastics, rubbers, adhesives), must satisfy the mechanical and electrical requirements of the system while being compatible with the chemical composition of the ink. This paper describes the selection and evaluation of these materials for a particular ink and printer design.

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Preface *by P. J. Flory, p. 98.*

Preparation and Properties of $(SN)_x$ *by G. B. Street and R. L. Greene, p. 99.* The chain compound $(SN)_x$ is the first example of a superconducting polymer. In this paper we review the chemistry, structure, and physical properties of $(SN)_x$ and describe how the electrical properties of this novel material depend upon the crystal growth technique. The thermal properties of S_2N_2 and $(SN)_x$ are discussed with particular reference to the crystal growth process. The fibrous nature of the polymer is described and evidence is presented showing that interchain coupling plays a significant role in determining the physical properties of this material. Finally we summarize our attempts to prepare analogous polymeric metals.

NMR Study of the Chain Microstructure of P(MMA-co-MAA) *by J. R. Lyerla, Jr., p. 111.* The usefulness of proton and carbon-13 NMR spectroscopy in characterizing the chain microstructure (i.e., sequence distribution and tacticity) of methyl methacrylate-methacrylic acid (MMA-MAA) copolymers has been investigated. Because the comonomers have such similar structures, assessment of chain tacticity and sequence distribution required computer simulation of spectra to circumvent the problems of resonance overlap. The computer analysis used ^1H and ^{13}C chemical shift data on homopolymers and "sterically-defined" copolymers, Bernoullian and Markovian statistics for the respective tactic and sequence distributions, and a Lorentzian lineshape program to generate a theoretical spectrum. The generating parameters that produced simulation of both the ^1H and ^{13}C spectra provided the basis for describing the triad microstructure of the copolymers. This method of characterizing the microstructure was applied to copolymers of similar composition but different preparative histories. The results indicated that free-radical polymerization in toluene yielded a heterogeneous copolymer system while free-radical polymerization in tetrahydrofuran (THF) and emulsion polymerization yielded relatively homogeneous systems.

Radiation Chemistry of Poly(methacrylates) *by H. Hiraoka, p. 121.* An experimental study comparing radiation-induced degradation of poly(methacrylates) from ultraviolet, gamma-ray (^{60}Co), and electron-beam irradiation is presented. Analytical techniques used include mass spectroscopy, low-temperature electron paramagnetic resonance, and infrared spectrometry. The poly(methacrylate) polymers investigated are poly(methyl methacrylate) (PMMA), poly(*t*-butyl methacrylate) (PBMA), poly(methacrylic acid) (PMA), and poly(methacrylic anhydride) (PMA AN). All are shown to exhibit scission of the main chains and removal of the side groups when irradiated.

Model for the Kinematics of Polymer Dissolution *by Y.-O. Tu and A. C. Ouano, p. 131.* The dissolution of glassy polymers is described by a phenomenological model of the motion of two boundaries: the liquid-gel boundary and the gel-glass boundary. The motion of these boundaries, as well as the concentration profile in the layers of a dissolving polymer, was obtained by numerical solution of the Stefan boundary value problem. Confirmation of the experimental program written to simulate the problem is established by its good agreement with direct observation of the dissolution dynamics of polystyrene in methyl ethyl ketone. A potential application of this model to the study of the dissolution dynamics of other polymer-solvent systems is done by simulating the dissolution of three types of polymer-solvent pairs: 1) swelling of rubber, 2) high glass transition concentration, and 3) low glass transition concentration. Contrasting dissolution characteristics are shown for the effect of different types of polymer-solvent pairs as well as for the effect of different molecular weights for the same type of polymer-solvent pair.

Parameters Affecting the Electron Beam Sensitivity of Poly(methyl methacrylate) *by E. Gipstein, A. C. Ouano, D. E. Johnson, and O. U. Need III, p. 143.* Poly(methyl methacrylate), PMMA, is used as a model polymer to determine quantitatively the effect of molecular weight, molecular weight distribution, and tacticity on electron beam sensitivity. The heterotactic, syndiotactic, and isotactic stereoforms of PMMA were synthesized with molecular weights ranging from 10^4 to 10^7 and dispersivities from 1.2 to about 10. The *G*-values as determined by gamma radiation are about 1.3 and are independent of the three parameters. However, the solubility rate of PMMA is very dependent on the tacticity, and the relative solubility rates are in the order syndiotactic < heterotactic isotactic. The weight-average molecular weight ratio was found to give a better correlation with solubility rate ratio than the number-average molecular weight ratio. The molecular size of the developer solvent was shown to have a much greater effect on the solubility rate than the molecular weight of the resist. An optimal developer solvent for PMMA can be systematically selected from a homologous series of *n*-alkyl acetates which enhance the resist sensitivity.

Strength and Related Properties of Elastomeric Block Copolymers *by T. L. Smith, p. 154.* Stress-strain curves of single-phase noncrystallizable elastomers over extended ranges of temperature and extension rate are considered qualitatively along with phenomenological and mechanistic aspects of fracture. Data are presented to show that single-phase noncrystallizable elastomers lack toughness except when segmental mobility is sufficiently low so that viscoelastic processes near the tip of a slowly growing crack effectively retard its growth. Highly effective strengthening mechanisms are imparted by plastic domains which result from phase separation in elastomeric block copolymers and from strain-induced crystallization in certain elastomers. The stiffness, tensile strength, and extensibility of a poly(urea-urethane) and three polyurethane elastomers over a broad temperature range are discussed in terms of the type, size, and concentration of the domain-forming segments. These elastomers, and particularly their true stress-at-break,

are compared with other block copolymers and with polyurethane elastomers devoid of plastic domains.

Properties of Polymeric Thin Films by Integrated Optical Techniques *by J. D. Swalen, R. Santo, M. Tacke, and J. Fischer, p. 168.* We report an innovative procedure for taking measurements using integrated optical techniques on a number of polymers fabricated into thin film form and used as optical waveguides. Refractive index (including anisotropy), absorption and scattering, and film thickness have been determined by light guiding properties. Techniques for film preparation, including doctor blading, dipping, horizontal flowing, and spinning, are also discussed. The polymers studied are poly(methyl methacrylate), poly(vinyl-formal), poly-acrylonitrile, poly(vinyl alcohol), poly(vinyl pyrrolidone), poly(vinyl benzoate), and polystyrene.

Solubility and Diffusion of Sulfur in Polymeric Materials *by B. S. Berry and J. R. Susko, p. 176.* Radiotracer techniques were used to study the sorption of sulfur vapor by silicone and epoxy polymers and to obtain information on the diffusion of sulfur in these materials. Sulfur was found to enter silicone polymers solely by a physical solution process which obeys Henry's law. The heat of solution is large (-0.43 eV) and at room temperature the solubility coefficient is at least five orders of magnitude greater than for many fully gaseous solutes, a result which fits an empirical rule relating the solubility coefficient of a given solute to its boiling point. Sorption of sulfur by a flexibilized anhydride-cured diglycidyletherbisphenol-A (DGEBA) epoxy is somewhat more complicated and appears to involve a double process of physical solution and chemical reaction. The rapid diffusion of sulfur in silicone rubber necessitated measurements of the diffusion coefficient D by a vacuum desorption technique. The activation energy Q and pre-exponential constant D_0 are found to be 0.74 eV and 4×10^5 cm^2/s, respectively. Corresponding values for the epoxy, as determined by a steady state permeation method, are 1.06 eV and 3×10^5 cm^2/s. These relatively large activation energies and pre-exponential factors are thought to reflect the large size of the S_8 molecule. Near room temperature, the difference in the activation energies causes sulfur diffusion to occur at least four orders of magnitude more slowly in the epoxy, which makes this material much more attractive for encapsulation applications requiring an effective diffusion barrier to elemental sulfur present as a pollutant of the atmosphere.

Rheology and Modeling of the Spin Coating Process *by B. D. Washo, p. 190.* This study examines the spin coating process both experimentally and from a fundamental point of view. The analysis has produced a model and a quantitative relationship between spin coating thickness and pertinent material and process variables. The model predicts that the simplest and most reproducible results occur in a region which is independent of thickness and time and is characterized by low steady state radial flow on the substrate. The model also includes a time-dependent term, shown to be important for the region of high radial flow—fluids of relatively low viscosity and process conditions of relatively high speed and/or long times. Experimentally, Newtonian-like polyamide in iso-amyl alcohol solutions was examined on large rotating substrates, and measurements showed excellent correlation with the model. The sensitivity of the spin coating process to substrate size and shape is also reported and a comparison with other data in the literature, particularly on photoresist solutions, is presented. The potential applicability of the model to non-ideal fluids is also developed.

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Thermal Effects on the Photoresist AZ1350J *by F. H. Dill and J. M. Shaw, p. 210.* An experimental study is reported on the various effects produced by the baking steps normally used in processing positive photoresists for application in microelectronics. The particular material investigated is AZ1350J, made by the Shipley Company, Inc. The thermal effects are studied in terms of a newly modified model that characterizes the exposure and development processes in photoresist. The changes in performance of the photoresist as a result of prebake, post-exposure bake, and post-development bake are discussed and are related to the parameters in the model that govern exposure and development. The model is derived from physical rather than chemical measurements.

Thermal Analysis of Positive Photoresist Films by Mass Spectrometry *by J. M. Shaw, M. A. Frisch, and F. H. Dill, p. 219.* Mass spectrometry is used to monitor the effect of temperature on positive photoresist and its two major components, a base resin and a photoactive compound. This technique is also used to identify the photolytic products of photoresist by exposing it in situ to ultraviolet radiation and to identify the resulting volatile products when it is heated after exposure. Quantitative data are obtained for the two major thermal products of photoresist, and the activation energy is calculated for the thermal degradation of the photoactive compound.

Conduction Studies in Silicon Nitride: Dark Currents and Photocurrents *by D. J. DiMaria and P. C. Arnett, p. 227.* Dark conduction and photoconduction phenomena in amorphous, stoichiometric Si_3N_4 films incorporated into metal-silicon nitride-silicon (MNS) structures are studied in detail. Results demonstrating the importance of hole conduction in Si_3N_4 thin films are presented. The importance of trapped space charge injected from the contacts is shown in an analysis of the effects of Si_3N_4 thickness and the choice of gate metal on conduction. Contact effects that are apparent in the current characteristics of thin Si_3N_4 layers become dominated by bulk conduction mechanisms as the silicon nitride film increases in thickness. Optical interference effects in photoconduction are used to determine the origin of photocarriers.

Automatic Signature Verification Based on Accelerometry *by N. M. Herbst and C.-N. Liu, p. 245.* The fine structure of the muscle forces that are exerted during the writing of a signature is constant and well defined for most people. In general, the fine structure is not subject to conscious control. Based on these observations, an experimental system has been designed that utilizes a person's signature dynamics to verify identities. The design and operational features of this system are described. Experiments on 70 subjects during a four-week period show a 2.9 percent rejection of valid signatures and a 2.1 percent acceptance of forgeries. An average of 1.2 trials was necessary for verification. The forgers were knowledgeable about the verification technique and did their best to deceive the system. The acceptance rate of random forgeries, i.e., accidental matching of two separate signatures, was 0.16 percent.

Discrete Link Capacity and Priority Assignments in Communication Networks *by K. Maruyama and D. T. Tang, p. 254.* This paper deals with the problem of discrete link capacity assignment in store-and-forward packet switching communication networks. Our problem formulation calls for minimizing the network cost while satisfying all the average packet delay constraints specified for different classes of packets. Heuristic algorithms which give near-optimal solutions of the problem are developed.

We first describe a discrete link capacity assignment algorithm for networks with arbitrarily defined classes of packets having individual delay constraints. The problem of priority assignment on different classes of packets is then investigated, and an algorithm is developed which assigns suboptimal priorities on classes of packets based on parameters such as delay requirement, path length, packet length, and packet rate. These two algorithms for capacity assignment and priority assignment are combined and tested over a number of examples. It is found that a substantial reduction on network cost can be achieved by the use of a simple priority queuing discipline.

Buffer Performance Analysis of Communication Processors During Slowdown at Network Control *by W.-M. Chow and L. Woo, p. 264.* An approximate model based on renewal theory has been developed for the performance analysis of communication processors during Network Control Program (NCP) slowdown. Performance values, which include cycle length, buffer utilization, and message loss, were computed as functions of traffic loads and user-assigned threshold values of free buffers were used for slowdown control. Comparison of results obtained by the approximate method with simulated results shows a high degree of accuracy for the approximation.

Improving the Computation of Lower Bounds for Optimal Schedules *by T. Lang and E. B. Fernández, p. 273.* Ways of decreasing the number of operations needed to compute the lower bounds of optimal schedules, by reducing the number of time intervals that must be considered, are presented. The bounds apply to a system of identical processors executing a partially ordered set of tasks, with known execution times, using a non-preemptive scheduling strategy. In one approach we find that the required number of intervals depends on the graph. In our other approach, which subsumes the first, the number of intervals is decreased to at most $\min[D^2/2, n^2]$, where D is the deadline to complete the tasks and n is the number of tasks. The actual number of intervals for a particular graph can be considerably smaller than this worst case.

Dynamic Memories with Faster Random and Sequential Access *by C.-K. Wong and D. T. Tang, p. 281.* This paper extends the dynamic memory proposed by Aho and Ullman in two directions. Instead of a shuffle permutation, block shuffles are introduced. By choosing suitable block sizes, faster random and sequential access may result. Another direction of extension comes from the addition of a reverse cyclic permutation, which results in even faster random and sequential access. Analyses for both the worst and the average cases are given. Generalizations to arbitrary radices are also discussed.

Capacitance Probe Study of Rotating-Head/Tape Interface *by N. A. Feliss and F. E. Talke, p. 289.* A modified version of the capacitance probe technique is used to investigate the head-tape interface in a rotating head configuration. The relationship between air-bearing spacing and contour design is studied as a function of tape tension, head protrusion, and velocity; in addition, the effect of wave dynamics on flying height is examined.

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Two-Dimensional Analysis of High-Voltage Power Transistors *by S. P. Gaur, p. 306.* The internal behavior of a typical n-p-n^--n^+ high-voltage power transistor is presented for several specific steady-state operating conditions obtained from a two-dimensional mathematical model. Internal self-heating and avalanche multiplication effects are taken into account. Poisson's equation, electron and hole continuity equations, and the heat flow equation are solved numerically in a two-dimensional region with the input parameters of device dimensions, doping profile, boundary conditions for external contacts, and various material constants for silicon. The collector n^--n^+ interface is the region of high electrical and thermal stress that causes second breakdown failure at high-voltage and high-current operating conditions. The combined effects of various high-injection levels are illustrated.

Splatter During Ink Jet Printing *by J. L. Zable, p. 315.* When an ink drop traveling at relatively high velocity impinges on a flat surface such as paper, part of the drop breaks up into many very small droplets that are deposited at other points. If these droplets are relatively large, then visible

splatter results. Various parameters (ink properties, drop velocity, drop volume, space between drops, etc.) are investigated to determine their effect upon splatter and hence print quality. Print samples were made while varying these parameters, and the resulting print quality was assessed. A simple relationship among the kinetic energy of the drops, the overlap between drops, and print quality based upon splatter is developed. This relationship can be used to establish design boundaries in an ink jet printer.

AUTOPASS: An Automatic Programming System for Computer Controlled Mechanical Assembly *by L. I. Lieberman and M. A. Wesley, p. 321.* This paper describes an experimental very high level programming system for computer controlled mechanical assembly, AUTOPASS (AUTOmated Parts ASsembly System). The AUTOPASS language is oriented towards objects and assembly operations, rather than motions of mechanical assembly machines. It is intended to enable the user to concentrate on the overall assembly sequence and to program with English-like statements using names and terminology that are familiar to him. To relate assembly operations to manipulator motions, the AUTOPASS compiler uses an internal representation of the assembly world. This representation consists of a geometric data base generated prior to compilation and updated during compilation; it thus represents the state of the world at each assembly step. The level of the language has been chosen to provide a high degree of assistance to the user without the system's having to perform artificial intelligence type problem solving operations.

Linear Filtering Technique for Computing Mersenne and Fermat Number Transforms *by H. J. Nussbaumer, p. 334.* In this paper, the implementation of pseudo-Mersenne and Fermat Number Transforms is discussed. It is shown that some pseudo-Mersenne Transforms can be computed efficiently by a linear filtering approach. This approach is extended to cover the case of Fermat and pseudo-Fermat Number Transforms by using a special coding scheme for implementing arithmetic operations in a Fermat number system.

Worst-Case Pattern Evaluation of Baseband Channels *by R. Kiwimagi, L. Griffiths, and R. Furtney, p. 340.* This paper presents a new method for evaluating the performance of communication systems that use binary-valued signaling formats. This technique permits selection of the best overall code for a particular channel or, alternatively, provides a method for comparing different channels that use the same transmission code. Encoded waveforms at the channel input are presumed to be generated by a constrained-coding procedure, which ensures, for example, that the resulting binary waveform has a certain minimum number of transitions per unit time, limited digital sum variations (DSV), among other characteristics. With this method, one first determines that particular sequence (within the given code constraints) that produces the maximum amount of intersymbol-interference when transmitted through the given channel. A dynamic-programming procedure is used to compute this sequence. Overall channel performance is evaluated by calculating the probability of error and the minimum eye-pattern opening. Numerical examples illustrating the procedure for a synthetic channel are presented and analyzed.

Algorithmic Information Theory *by G. J. Chaitin, p. 350.* This paper reviews algorithmic information theory, which is an attempt to apply information-theoretic and probabilistic ideas to recursive function theory. Typical concerns in this approach are, for example, the number of bits of information required to specify an algorithm, or the probability that a program whose bits are chosen by coin flipping produces a given output. During the past few years the definitions of algorithmic information theory have been reformulated. The basic features of the new formalism are presented here and certain results of R. M. Solovay are reported.

Heuristic Design Algorithm for Computer Communication Networks with Different Classes of Packets *by K. Maruyama, L. Fratta, and D. T. Tang, p. 360.* A typical operating environment of a packet switching (store-and-forward) computer communication network is that it is shared by many users with different classes of packets. Packets may be classified in a very general fashion by types of users, messages, applications, transactions, response time requirements, packet parameters such as packet rate and length, and by network parameters such as source-destination and path length. A well-designed network must provide access and performance assurance to all packet classes. This paper presents a heuristic algorithm for designing such a communication network. The algorithm presented contains heuristic algorithms for discrete link capacity assignment, priority assignment, and flow assignment problems with an additional feature which allows one to alter network topology interactively. Sample results from applications of the overall network design are also given.

Queuing Networks with Population Size Constraints *by S. S. Lam, p. 370.* The class of queuing networks with multiple routing subchains is extended to include mechanisms of state-dependent lost arrivals and triggered arrivals. A sufficient condition is found, involving the loss and trigger functions, for the equilibrium network state probability distribution to have the product form; the known class of queuing networks with a product form solution is thus enlarged. Such queuing networks are useful models for systems with various population size constraints. Potential applications to modeling computer communication systems with storage and flow control constraints are indicated.

Experiments on the Dynamic Response of a Flexible Strip to Moving Loads *by D. M. Albrecht, E. G. Laenen, and C. Lin, p. 379.* Experimental findings are reported on the dynamic response of a flexible strip to moving loads traveling

at an oblique angle to its edges. The strip is wrapped under tension around a pair of supporting pressurized cylinder halves. The moving loads are applied to the flexible strip at the gap between the two cylinder halves. A capacitance displacement transducer measures the dynamic response of the strip, which is shown in isometric perspective for various boundary conditions. It is shown that waves on the strip created by the moving loads can be eliminated by providing a hydrodynamic air film support to the flexible strip in the vicinity of the moving loads. Experiments demonstrate that response to the loads along the edges of the strip differs from that near its center, which is to be expected because of the reflection of flexural waves from the boundaries of the strip.

An Extension of Moore's Result for Closed Queuing Networks *by S. S. Lam, p. 384.* In this communication, Moore's result for the normalization constant of a closed queuing network of exponential servers is extended to the case of nondistinct traffic intensities. We then show that this result can be applied to various more general closed and semiclosed queuing networks with a product-form solution.

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Analysis of the Merged Charge Memory (MCM) Cell *by H.-S. Lee, p. 402.* This paper describes a new MOS dynamic RAM (Random-Access Memory) cell which utilizes a merged surface charge transistor structure. The merged charge memory (MCM) cell uses a polysilicon electrode as both a bit sense line and common plate for a column of storage capacitors. The MCM structure is self-aligned, contactless and free of closely spaced *p-n* junctions. Its spatial density approaches the conceptual limit of the intersection formed by two orthogonal lines or $4W^2$ where W is the minimum geometry feature. The cell area utilization efficiency is improved because of this simplicity. Preliminary experimental results and ASTAP simulations based on the charge control equivalent circuit for a dynamic potential well are described. Implications for chip design constraints are discussed, and the advantages and limitations of MCM are highlighted where appropriate.

Digital Technique for Generating Synthetic Aperture Radar Images *by W. J. van de Lindt, p. 415.* This paper describes a digital processing method applicable to a synthetic aperture radar, to be carried by the space shuttle or by satellites. The method uses an earth-fixed coordinate system in which corrective procedures are invoked to compensate for errors introduced by the satellite motion, earth curvature, and wavefront curvature. Among the compensations discussed are those of the coordinate system, skewness, roll, pitch, yaw, earth rotation, and others. The application of a Fast Fourier Transform in the numerical processing of the two-dimensional convolution is discussed in detail.

Safe Operating Area for Bipolar Transistors *by S. P. Gaur, p. 433.* A mathematical model is utilized to predict the safe operating area (SOA) for proper circuit applications of bipolar transistors in the forward as well as reverse operating regions. Nonuniformity of the temperature within the transistor structure due to internal self-heating and the avalanche multiplication effect in the reverse operating region, which cause second breakdown failure, are taken into account. Steady-state electrical and time-dependent thermal problems are solved to establish stability of a specified operating condition. Safe operating area curves for three transistor designs of similar power handling capability are presented. Current density and temperature distributions within the transistor structure for various operating conditions in the stable as well as unstable regions are presented. Suitability of V_{BE} to estimate peak temperature within the device is discussed.

Multidimensional Bin Packing Algorithms *by L. T. Kou and G. Markowsky, p. 443.* A comparative study is made of algorithms for a general multidimensional problem involving the packing of k-part objects in k compartments in a large supply of bins. The goal is to pack the objects using a minimum number of bins. The properties and limitations of the algorithms are discussed, including k-dimensional analogs of some popular one-dimensional algorithms. An application of the algorithms is the design of computer networks.

Zero Order and Nonzero Order Decision Rules in Medical Diagnosis *by R. J. Peters, p. 449.* In searching for the optimal solution to the medical diagnostic problem, it seems useful to distinguish between different possible decision rules (strategies). Two different classes of decision rules are considered: nonzero order decision rules and constant or zero order decision rules. For each class, solution methods as well as heuristic approaches to finding the optimal member of the class are discussed. As an exercise, the diagnosis of a hematologic disease belonging to the group macrocytic anemia is considered.

Variable Geometry Cochlear Model at Low Input Frequencies: A Basis for Compensating Morphological Disorders *by A. Inselberg, p. 461.* The implementation of an algorithm suitable for interactive experimentation with a mathematical model of the cochlea is described. In the model, the cochlea's exterior shell is represented by a surface of revolution. Internally, the cochlea is partitioned symmetrically into two chambers (the scalae) by a midplane representing the basilar membrane with its bony supports together with the "collapsed" cochlear duct (third chamber). The two chambers are filled with a viscous and incompressible fluid and communicate through a small opening (the helicotrema), at the cochlea's apex. The system is driven by the piston-like movement with frequency ω of the stapes at the cochlea's basal end. An isotropic sectorial plate widening toward the apex represents the basilar membrane. Some of the effects of the cochlear duct are considered through a provision for nonzero net pressure at the basilar membrane's apical end. The behavior of this system in the

neighborhood of the low-frequency threshold, where the effects of cochlear geometry are most pronounced, is described from the solutions of the equations of motion for $\omega \rightarrow 0$.

Laser-Optical System of the IBM 3800 Printer *by J. M. Fleischer, M. R. Latta, and M. E. Rabedeau, p. 479.* A helium-neon laser, acousto-optical modulator and rotating polygonal mirror are used for the optical design of a computer printout system. This combination of technologies in the printer produces high-quality nonimpact printing at speeds of 23,000 to 52,000 characters per second. A new technique utilizing a cylindrical/toroidal lens pair is described which reduces, by two orders of magnitude, scan line displacement errors produced by the polygonal mirror. The optical design principles and alignment techniques used in the assembly are shown.

Comment on "Decomposition of a Data Base and the Theory of Boolean Switching Functions" *by C. Delobel, R. G. Casey, and P. A. Bernstein, p. 484.*

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Automatic Registration in an Electron-Beam Lithographic System *by D. E. Davis, R. D. Moore, M. C. Williams, and O. C. Woodard, p. 498.* In the fabrication of integrated circuits, electron-beam systems are increasingly used to directly expose circuit patterns on resist-covered semiconductor wafers. These systems are made attractive by their inherent capability for writing patterns at high resolution, which eliminates the need for the masks used in optical exposure systems. To compete economically in production, electron-beam systems must attain a high level of wafer throughput. To achieve this, the system must be fully automated and spend the minimum of time in performing overhead functions such as various calibrations, pattern registration, and mechanical positioning of the wafers. This paper describes pattern registration, a process by which the circuit patterns required at a particular level of device fabrication are mapped to those of the preceding level. It discusses the considerations taken as basic in designing an accurate, high-speed registration process for a production-type electron-beam exposure system. This automatic registration system operates in 150 milliseconds per integrated circuit chip, allowing the system to achieve a throughput of 2000 5-mm chips per hour with overlay error of less than 0.75 μm (3σ). The operation of this system, its performance characteristics, and measurements of its pattern-matching accuracy are presented.

Correction of Nonlinear Deflection Distortion in a Direct Exposure Electron-Beam System *by H. Engelke, J. F. Loughran, M. S. Michail, and P. M. Ryan, p. 506.* This paper describes a distortion correction technique, used in a high-throughput electron-beam exposure system, which achieves an absolute deflection accuracy of about 30 parts per million (ppm) throughout a 5-mm field. To accomplish this, a cyclic, numerically controlled magnetic deflection with an accuracy of about 1000 ppm and high repeatability is first established. Horizontal and vertical errors in this deflection are measured by sensing the apparent locations of features in a calibration grid that is placed in the exposure field of the beam. The measured error is smoothed by means of a two-dimensional spline-fitting method, and the parameters for the correction surfaces are calculated. Corrections to position and speed, defined by a set of digital tables, are superimposed on the basic deflection, and the process is iterated until acceptable precision is achieved. Parameters relating registration scans to field-writing scans are then calculated for use in the registration of all written fields.

Electron Optics of an Electron-Beam Lithographic System *by J. L. Mauer, H. C. Pfeiffer, and W. Stickel, p. 514.* This paper describes the electron optics of a practical scanning electron-beam lithographic system (EL1) that provides high-volume direct wafer exposure. The throughput limitation inherent in serial exposure is greatly reduced by exposing entire pattern segments with a shaped beam. The shaped-beam concept represents a combination of scanning and projection methods. Twenty-five image points are exposed simultaneously to increase the spot current accordingly over that of a Gaussian round-beam system that exposes one image point at a time. The higher total current could lead to intensified Coulomb interaction between beam electrons, causing excessive Boersch effect and additional aberrations. However, the imaging and deflection methods described here are shown, by theoretical and experimental means, to reduce both the effects of Coulomb interaction and the total aberration of the system. This results in improvement of the beam current and field coverage compared with those found in conventional systems.

Control of Magnetic Properties During the Processing of Single Crystal Garnet Films *by J. E. Davies, p. 522.* Thin single-crystal rare earth iron garnet films are currently the most attractive materials for magnetic bubble domain applications. To utilize their potential, tight control of the magnetic properties is needed at each of the film processing steps. Such steps include the growth of large-area films from a supersaturated $PbO\text{-}B_2O_3$ fluxed melt, the phosphoric acid trimming of as-grown films to adjust the bubble collapse field, ion implantation of the film surface to suppress the formation of hard bubbles and the subsequent annealing the implanted layer receives during the thermal cycling of the device fabrication steps. Control of film properties at each of these stages will be discussed and data presented to show how each of these stages may be optimized.

Permutation Clustering: An Approach to On-Line Storage Reorganization *by B. T. Bennett and P. A. Franaszek, p. 528.* A class of dynamic reorganization algorithms is described which embodies a number of desirable systems properties. Experiments on a trace taken from a large data base application indicate that a member of this class may be

used to obtain time-varying or quasistatic organizations that exhibit improved paging performance.

Functional Dependencies in a Relational Database and Propositional Logic *by R. Fagin, p. 534.* An equivalence is shown between functional dependency statements of a relational database, where "$\rightarrow$" has the meaning of "determines," and implicational statements of propositional logic, where "$\Rightarrow$" has the meaning of "implies." Specifically, it is shown that a dependency statement is a consequence of a set of dependency statements iff the corresponding implicational statement is a consequence of the corresponding set of implicational statements. The database designer can take advantage of this equivalence to reduce problems of interest to him to simpler problems in propositional logic. A detailed algorithm is presented for such an application. Two proofs of the equivalence are presented: a "syntactic" proof and a "semantic" proof. The syntactic proof proceeds in several steps. It is shown that 1) Armstrong's Dependency Axioms are complete for dependency statements in the usual logical sense that they are strong enough to prove every consequence, and that 2) Armstrong's Axioms are also complete for implicational statements in propositional logic. The equivalence then follows from 1) and 2). The other proof proceeds by considering appropriate semantic interpretations for the propositional variables. The Delobel-Casey Relational Database Decomposition Theorems, which heretofore have seemed somewhat fortuitous, are immediate and natural corollaries of the equivalence. Furthermore, a counterexample is demonstrated, which shows that what seems to be a mild extension of the equivalence fails.

Sequential Stopping Rules for the Regenerative Method of Simulation *by S. S. Lavenberg and C. H. Sauer, p. 545.* We consider the estimation via simulation of confidence intervals for steady-state response variables for stochastic systems which have a regenerative stochastic structure. Sequential stopping rules are investigated which allow the ratio of the width to the mid-point of an estimated confidence interval to be specified ahead of time. We prove that the resulting confidence intervals are valid asymptotically as the relative width decreases to zero. For various relative widths we empirically investigate the validity of the confidence intervals obtained when the stopping rules are applied to the simulation of queuing systems having a regenerative stochastic structure. For the queuing systems and response variables considered, a relative width of 0.05 is found to be sufficiently small to yield valid confidence intervals in almost all cases. In addition, we empirically compare the sequential stopping rules with a fixed stopping rule.

Data Flow Analysis in the Presence of Procedure Calls *by D. B. Lomet, p. 559.* The aliasing that results in a variable being known by more than one name has greatly complicated efforts to derive data flow information. The approach we take involves the use of a series of claims that, after we compute the data flow for some of the aliasing possibilities, allows us to produce good approximations for the remaining cases. The method can thus limit the potential combinatorial explosion of aliasing computations while providing results that are frequently exact and almost always very good. The method is illustrated in the context of data flow analysis involving multiple procedures and their calling interactions. It is applicable also in the treatment of recursive procedures.

Potential Significance to Neurophysiology of Design Algorithms for Digital Computers *by R. D. Traub and J. P. Roth, p. 572.* A set of algorithms has been developed within the computer industry that aids in the design and comparison of large switching circuits. To apply these algorithms to the nervous system in a realistic way, it is necessary to find neurons where (a) the electrophysiological data exist to allow construction of a plausible model; and where (b) the behavior of the neuron is not dependent on its distant past, so that the cell may be approximated by a switching circuit. It is also necessary to find areas of the nervous system whose structure resembles that of so-called regular designs; a regular design is a logic circuit in which feedback loops are constrained to take certain simple forms. In cases where local feedback loops are an intricate part of the design (as is true in virtually all areas of the mammalian central nervous system), this constrains one to analyze the behavior of the area in question only over time intervals sufficiently short so that such feedback loops can be ignored. Certain areas, such as the retina, are excluded because the individual neurons behave nondiscretely and are intimately coupled together (i.e., the retina does not resemble a regular design).

Effect of Substrate Bias on Properties of RF-Sputtered Cr-SiO Films *by H. Matino and T. Ushiroda, p. 576.* Properties of rf-sputtered Cr-SiO cermet films have been studied as a function of rf substrate bias. Films with five orders-of-magnitude change in electrical resistivity have been deposited from one Cr-SiO(50:50 wt %) target by changing the substrate bias. Resistivities of about 200 $\Omega \cdot$ cm at 5% bias and about 2×10^{-3} $\Omega \cdot$ cm at 20% bias have been obtained.

Origin and Effects of Negative Ions in the Sputtering of Intermetallic Compounds *by J. J. Cuomo, R. J. Gambino, J. M. E. Harper, and J. D. Kuptsis, p. 580.* An unexpected etching phenomenon during the sputtering of rare earth-gold alloys has been found to be caused by a large flux of negative gold ions from the sputtering target. We find this effect to occur in a range of intermetallic compounds. A model is presented which predicts when negative ion formation will be important. Effects of negative ions on sputter deposition of thin films include reduced deposition rate or substrate etching, and changes in film composition and other properties. Negative ion formation must also be taken into account for accurate quantitative analysis by Secondary Ion Mass Spectrometry (SIMS).

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Control of the IBM 3800 Printing Subsystem *by G. I. Findley, D. P. Leabo, and A. C. Slutman, p. 2.* The IBM 3800 Printing Subsystem is controlled by a high speed multilevel, interrupt-driven microprocessor. The design of this system has included several innovative concepts to take advantage of the flexibility of electrophotographic laser printing. New functions that are introduced include intermixed pitches, fonts, and line spacings; user-alterable character sets; on-line forms generation; and superior retry, fail-soft and diagnostic capabilities. Compatibility with the operational characteristics of IBM 1403 and 3211 printers is maintained. This paper discusses many of the objectives, development tradeoffs, and resultant control implementations for an on-line computer output printing subsystem.

Paper Path of an On-Line Computer-Output Printer *by R. G. Svendsen, p. 13.* This paper describes the development of a paper handling system designed to move paper at a speed of 81 cm/s in the IBM 3800 Printing Subsystem. During the development of the printer a number of unique problems arose from the interaction among paperline components. The various approaches and solutions to these problems, including paper path alignment, character stretch, registration within the fuser, and path error detection, are discussed and illustrated.

Paper Servo Design for a High Speed Printer Using Simulation *by T. J. Cameron and M. H. Dost, p. 19.* The design of feedback systems for control of paper motion through the IBM Printing 3800 Subsystem is described. The main tool for analysis and optimization is DSL, a digital simulation language for systems of continuous nature. The several stages in the evolution of the design are discussed.

Design of the Fusing System for an Electrophotographic Laser Printer *by K. D. Brooms, p. 26.* This paper discusses the development and design of the fusing system used in the IBM 3800 Printing Subsystem. The design solutions provide satisfactory fusing of powdered toner print images to paper at a processing rate of 81 cm/s under a variety of operating conditions.

Electrophotographic Process in a High Speed Printer *by U. Vahtra and R. F. Wolter, p. 34.* The IBM 3800 printing subsystem was developed for on-line computer system output printing in hard copy form at high speeds. The subsystem combines laser and electrophotographic technology with a multiformat paper handling system and on-line character set variability to provide increased data handling flexibility, throughput and print quality at reduced cost. This paper presents design considerations for the electrophotographic process. It provides an overview of the process and discusses methods and technical approaches used in the design of the printer.

Light Scattering Study of Structures in a Smectic Liquid Crystal *by W. H. Chu and J. T. Jacobs, p. 40.* The effect of surface treatment, sample thickness, and cooling rate on the structural order in the smectic phase of *p-n*-octyl-*p'*-cyano-biphenyl has been investigated by light scattering, and the results have been interpreted in terms of theories developed for crystalline polymers. Fan-shaped superstructures are found when the long dimension of the liquid crystal molecules is aligned parallel to the wall of a cell. But banded two-dimensional spherulites exist when the long dimension of the molecules is aligned perpendicular at one wall and parallel at the opposite wall. Uniaxially oriented rodlike structures are observed when the wall surface is lapped. Because surfaces have a strong effect, the superstructures are less highly ordered in thick than in thin cells. With an increase in cell thickness, the size of the superstructures increases along with the degree of disorder. If a sample is cooled rapidly to the solid state and then heated to the smectic state, the order in the smectic liquid crystal is reduced, as shown by a marked increase in the effect of density fluctuations on light scattering patterns. In a sample cooled slowly from the nematic to the smectic state, light scattering results primarily from orientation fluctuations.

Phase Equilibria in Liquid Crystal Mixtures *by R. J. Cox and J. F. Johnson, p. 51.* The thermodynamic relationships for mixtures of nonmesomorphic compounds are applied to liquid crystalline materials. Equations developed for ascending solid solutions have been applied to mixtures of liquid crystalline materials. Computer programs, written to calculate the theoretical curves for such mixtures, are found to agree with the experimental data obtained for 4-alkyl and 4-alkoxy 4'-cyanobiphenyls and a series of *p,p'*-dialkoxyazoxybenzenes. The heats and temperatures of the transitions of the pure components, necessary for the theoretical calculations, were determined by polarized light microscopy and by differential thermal analysis. Polarized light microscopy was also used to determine the transition temperatures of the mixtures.

Automated Validation of a Communications Protocol: the CCITT X.21 Recommendation *by C. H. West and P. Zafiropulo, p. 60.* The call establishment procedure of the X.21 interface recommended by the International Telegraph and Telephone Consultative Committee (CCITT) has been validated as a test of a recently developed theory and of an implemented system for automated communications protocol validation. The test demonstrated the applicability of the validation technique and identified a number of points where the interface state diagram does not completely define the interface behavior.

Relation Between an Atomic Electronegativity Scale and the Work Function *by H. B. Michaelson, p. 72.* Recently compiled data for the first electron affinity and the first ionization potential are used to obtain values for an atomic electronegativity scale, based on the Mulliken relation. From this scale and a new compilation of work function data, a

linear equation is obtained which includes a parameter for any given element, depending on its subgroup in the periodic table. Data are plotted for 51 elements, including simple metals, transition metals, and semiconductors. These data fit the straight-line equation better than 10 percent. Data for the transition metals deviate within the same limits as those for elements having simpler electronic configurations. The electronegativity scale differs significantly from the Pauling scale and is shown to be a useful guide to preferred values of the work function for elements.

Data Acquisition and Reduction Program for Thermogravimetry *by A. Doelman, A. R. Gregges, and E. M. Barrall II, p. 81.* An on-line data acquisition system for thermogravimetry using the IBM S/7 computer followed by data reduction on a 360/195 is described by means of flow charts. The system is designed so that no knowledge of programming is required to acquire, display and manipulate data on an interactive graphics terminal. The program not only extracts weight loss data, but also computes the energies of activation, *E*, for any selected weight loss interval by two methods, i.e., tabular integral and derivative. The system is demonstrated by a study of the activation energies for loss of water, loss of carbon monoxide, and loss of carbon dioxide during the thermal decomposition of calcium oxalate monohydrate. The results are in good agreement with the best literature values. The derivative method was found to give more consistent results than the tabular integral approach because of problems encountered in the precise measurement of temperature in the thermobalance.

Influence of Jet Printing Inks on Wear *by R. G. Bayer and J. L. Sirico, p. 90.* This communication reports the results of wear tests performed to determine the influence of jet printing inks on the wear of several polymer-metal pairs, which were known to be compatible with the inks. It is shown that these inks generally tend to increase wear beyond that occurring in a dry state. The principal reason for this increase was concluded to be the adverse influence that the inks have on the establishment of a beneficial transfer film on the metal surface.

***IBM Journal of Research and Development*: Information for Authors** *by R. J. Joenk, p. 94.* This paper combines background information about the *IBM Journal of Research and Development* with guidelines for the preparation of *Journal* manuscripts. The purpose is to acquaint authors with the *Journal* as a primary, professional publication and to present suggestions to ease the work of author and editor in preparing clear, concise, and useful manuscripts.

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Novel Materials and Devices for Sunlight Concentrating Systems *by H. J. Hovel, p. 112.* Photovoltaic conversion under concentrated sunlight is a highly promising technique that could make solar-electric power generation economically competitive with fossil fuel power generation by the mid-1980s. An economic analysis has been performed which demonstrates that solar cell efficiency, concentrator efficiency, and concentrator cost are the most important parameters in a concentrating photovoltaic system; solar cell cost is only of secondary importance (at least for Si solar cells). Six novel structures are described, including modified conventional Si cells, $Ga_{1-x}Al_xAs/GaAs$ devices, interdigitated cells, vertical and horizontal multijunction cells and "multicolor" devices.

Solar Radiative Heating in the Presence of Aerosols *by P. Halpern and K. L. Coulson, p. 122.* A theoretical study is carried out to evaluate the effects of aerosols on the shortwave flux divergence in the lower troposphere (0–2 km) by using four computational methods: *Gauss-Seidel iteration,* a reference method by which all orders of scattering are accounted for, and three approximations, *primary scattering, no-scattering* and *median wavelength.* By using these procedures, the radiative transfer equation is solved for a cloudless plane parallel atmosphere of infinite extent in the horizontal, but of finite extent in the vertical. The Gauss-Seidel procedure is taken as a standard and comparisons of the flux divergence are made by using various combinations of solar zenith angle, aerosol size frequency distribution and aerosol refractive index. In many of the simulations the median wavelength approximation gives accuracies comparable to those of the no-scattering approximation, in which case the choice of method is based on the required computational time. However, inaccuracies appear with all the approximations and the degree of superiority of one method over another depends on the aerosol and gaseous constituents of the model atmosphere.

Computation of Convolutions and Discrete Fourier Transforms by Polynomial Transforms *by H. J. Nussbaumer and P. Quandalle, p. 134.* Discrete transforms are introduced and are defined in a ring of polynomials. These polynomial transforms are shown to have the convolution property and can be computed in ordinary arithmetic, without multiplications. Polynomial transforms are particularly well suited for computing discrete two-dimensional convolutions with a minimum number of operations. Efficient algorithms for computing one-dimensional convolutions and Discrete Fourier Transforms are then derived from polynomial transforms.

Language Facilities for Programming User-Computer Dialogues *by J. M. Lafuente and D. Gries, p. 145.* Extensions to PASCAL that provide for programming man-computer dialogues are proposed. An interactive application program is viewed as a sequence of *frames,* representing stages of dialogue activity, and separate computational steps. First, extensions are presented to allow the description of the items of information contained in each frame. Second, PASCAL is extended to allow the inclusion of *behavior rules* for a frame to specify the interactive dialogue. The behavior rules are specified nonprocedurally. Previously, programming such

dialogues has required the specification of all possible interactions and their effects in a procedural fashion.

Variational Principles for Semiconductor Device Modeling with Finite Elements *by J. H. Hohl, p. 159.* Variational principles related to three areas of semiconductor device modeling by the finite element method are presented. Some subtle points which are crucial to the successful application of the method are explored. It is suggested that the validity of the selected variational formulations must be carefully ensured, and that the physics disciplines provide the best guidance for the right selections.

Convex Cubic Splines *by B. Dimsdale, p. 168.* Control curves used in industry are usually planar cubic splines, continuous and single-valued for a specific independent variable. If large slopes are specified at certain points, the spline coefficients, which are computed in order to preserve second derivative continuity of the spline, invariably lead to wildly oscillatory curves. Normally the large slopes occur at the ends of the curve, and this paper deals with such cases, developing methods which have been used successfully to combat the problems encountered. The end point where the difficulty occurs is ignored for the moment and a curve (spline or not) is designed for the remaining points. Then, with the point and slope adjacent to the difficult point known, the design is completed with one or more spline segments so that the resulting curve, which connects the difficult point to the next point, is convex (or concave), and has at least first derivative continuity. For the large finite slope case, two methods are described. The first method constructs the desired curve as a sequence of spline segments with finite slope everywhere, whereas the second expands the interval so that a single spline segment with infinite end slope passes through the difficult point with the required slope. The case of infinite end slope is also treated. In this and the preceding cases, second derivative continuity can be preserved at the juncture under certain conditions.

Steady Axisymmetric Solutions for Pressurized Rotating Flexible Disk Packs *by D. B. Bogy and F. E. Talke, p. 179.* Steady solutions are obtained for undisturbed pressurized flexible disk packs of various configurations. Simplified fluid equations of motion are coupled with the equations governing the deflection of flexible membranes in order to arrive at the differential equations for the spacing between the disks of the pack. A simple asymptotic-solution formula is derived for computing the dependence of the spacing between two neighboring disks on air density and viscosity, the volume rate of flow of air between the two disks, the angular speed of rotation, and the radial position on the disks.

Effect of Replacement Algorithms on a Paged Buffer Database System *by E. B. Fernández, T. Lang, and C. Wood, p. 185.* In a database system a buffer may be used to hold recently referenced pages. If this buffer is in virtual memory, the database paging system and the memory paging system affect its performance. The study of the effect of main memory replacement algorithms on the number of main memory page faults is the basic objective of this paper. We assume that the buffer replacement algorithm is least recently used (LRU), and page fault rates for LRU, random (R), and generalized least recently used (GLRU) main memory replacement algorithms are calculated and compared. A set of experiments validates these fault rate expressions and establishes some conditions for the practical application of the results.

Model for Database Reference Strings Based on Behavior of Reference Clusters *by M. C. Easton, p. 197.* The observation that references to a particular page are clustered (in time) in typical database reference strings is used as the intuitive motivation for a model of page reference activity in an interactive database system. The model leads to a two-parameter form for the (Denning) working-set functions associated with a page. Methods for estimating parameter values from measurements or from logical descriptions of applications are discussed. Results from the model are shown to agree well with measurements from two database systems.

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Preface *by E. Kay, p. 212.*

Model Study in Chemisorption: Molecular Orbital Cluster Theory for Atomic Hydrogen on Be(0001) *by C. W. Bauschlicher, Jr., P. S. Bagus, and H. F. Schaefer III, p. 213.* The interaction between atomic hydrogen and the (0001) surface of Be has been studied by using clusters of Be atoms to simulate the substrate. The largest cluster used contains 22 Be atoms, 14 in the first layer and 8 in a second layer. An H atom is added to the Be clusters at four high symmetry adsorption sites. *Ab initio* molecular orbital Hartree-Fock wave functions have been obtained and the interaction energy of H with the Be cluster is studied as a function of vertical distance from the surface. Thorough studies of various aspects of the computations and of the appropriate interpretation of the cluster results are reported. Our results show that three of the sites considered have similar binding energies, $D_e \approx 50$ kcal/mol ($\approx 2.1 \times 10^5$ J/mol), and (vertical) equilibrium distances from the surface, $r_e \approx 0.1$ nm. For the fourth site, H directly over a Be atom, D_e is ≈30 kcal/mol (1.3×10^5 J/mol), and r_e is ≈0.14 nm. We expect that the dissociative adsorption of H_2 on Be(0001) will be exothermic. A model calculation for diffusion of H into the bulk indicates that this process is energetically unfavorable for an ideal (0001) surface. The vibrational energies for the motion of H normal to the surface are found to be substantially different for sites with different surface coordinations. The nature of the covalent bond formed between H and Be(0001) is analyzed.

Core-Level Photoemission and LEED Studies of Adsorption at Fe Surfaces: Comparison Between CO and

O_2 *by C. R. Brundle, p. 235.* Carbon monoxide and oxygen interactions with α Fe(100) and polycrystalline surfaces have been studied by x-ray photoemission (XPS or ESCA) and low energy electron diffraction (LEED) at temperatures between 123 K and 473 K. For CO, the XPS results demonstrate the existence of four electronically distinct CO adsorption states; one is dissociative and three are molecular. The binding energy analyses are consistent with one of the latter molecular adsorption states, formed on the polycrystalline surface, having a stretched CO bond compared with the equivalent state on the Fe(100) surface. For oxygen, only dissociative chemisorption is observed, even at 123 K. Assuming monolayer coverage at saturation allows calibration of the coverage for all other situations of CO and O_2 adsorption. It is demonstrated that at coverages of just greater than a monolayer (293 K adsorption), Fe oxide species are already present and that Fe^{III} dominates. Studies at grazing angles, designed to enhance the surface sensitivity of the core-level measurements, fail to reveal recognizable Fe^{II} or Fe^{III} species much below monolayer coverage even though LEED studies indicate that an FeO-like geometric structure has developed at coverages much lower than this.

Reaction of Atomic Hydrogen with Si(111) Surfaces: Formation of Monohydride and Trihydride Phases *by K. C. Pandey, p. 250.* By using a realistic tight-binding or LCAO (linear combination of atomic orbitals) model, detailed calculations of surface states, local densities of states, and theoretically simulated photoemission spectra have been carried out for two qualitatively distinct structural models for chemisorption of atomic hydrogen on Si(111)1×1 surfaces. In the low-coverage model, called the monohydride phase or Si(111):H, it is assumed that a single hydrogen atom sits on top of each surface Si atom, thus saturating all dangling bonds. In the high-coverage model, designated as the trihydride phase or Si(111):SiH_3, SiH_3 radicals are bonded to the surface Si atoms. Due to the radically different atomic structures, the theoretical spectra of the two phases show striking differences. A comparison of the theoretical spectra with the ultraviolet photoemission spectra taken during hydrogen chemisorption on the quenched Si(111)1×1 surface clearly shows that at low coverages the monohydride is formed, while at high coverages the trihydride phase is formed. Formation of the monohydride phase is expected on simple chemical and structural considerations, and it has been observed on other Si surfaces. However, formation of the trihydride phase is unique to Si(111)1×1 and as such, it has important implications regarding the structure and stability of clean Si(111)1×1.

Chemisorption of Ethane on W(111) *by H. F. Winters, p. 260.* Ethane is chemisorbed on W(111) with a sticking probability of ≈0.003. The carbon Auger spectrum at saturation coverage exhibits a two-peak structure similar to that for graphite, while the LEED (low energy electron diffraction) pattern is almost identical to that obtained for an atomically clean surface. Heating the surface to ≈773 K causes desorption of hydrogen and changes the carbon Auger spectrum to a three-peak structure similar to that for tungsten carbide. After annealing, the LEED pattern is affected in different ways depending on the precise conditions, but it may in certain circumstances almost disappear. Exposure to ethylene produces a similar sequence of events. A large kinetic isotope effect is observed with the ratio of the sticking probabilities [$S(C_2H_6)/S(C_2D_6)$, W(111), $T = 300$ K] being ≈3. A similar ratio is measured for tungsten at $T = 2500$ K. These data suggest that chemisorption is dissociative in nature, probably involving the reaction $C_2H_6 \rightarrow C_2H_5^* + H \rightarrow$ subsequent steps. Heating of the surface completely dissociates the adsorbed gas, leaving adsorbed carbon and gas phase hydrogen. In analogy with previous work on methane, we believe the large isotope effect suggests that the initial dissociation reaction is dominated by the tunneling of a hydrogen atom through a potential barrier. The implications of this conclusion for other saturated molecules will be discussed.

Molecular Geometries of Acetylene and Ethylene Chemisorbed On Cu, Ni, Pd, and Pt Surfaces *by J. E. Demuth, p. 265.* Ultraviolet photoemission measurements of the valence orbital electronic structure of acetylene and ethylene chemisorbed on Cu(100) or Cu(111), Ni(111), Pd(111), and Pt(111) are presented. We compare the measured energy levels of these chemisorbed species to those of the free molecule and use a similar comparison of the relative changes in ground state energy levels of distorted free molecules calculated with a SCF-LCAO (Self Consistent Field—Linear Combination of Atomic Orbitals) method to determine the molecular geometries of these chemisorbed species. The limitations and accuracies of such an approach are discussed. From the determined geometries we identify two trends in the structure of these chemisorbed molecules on these surfaces: first, increasingly greater molecular distortions occur with increasing atomic number of the substrate atom, and secondly, greater molecular distortions occur for ethylene than for acetylene on the same metal. These trends are consistent with a π-d bonding interaction and can be accounted for by the electronic structure of the substrate and of the molecule, respectively. With the exception of ethylene on Pd or Pt, we determine molecular geometries characteristic of small rehybridization. The molecular geometry of ethylene on Pd or Pt is generally characteristic of rehybridization to an sp^3 configuration.

Sputter Profiling Through Ni/Fe Interfaces by Auger Electron Spectroscopy *by T. J. Chuang and K. Wandelt, p. 277.* Sputter characteristics of nickel-iron systems in the form of layer interfaces and bulk alloy films have been studied by Auger electron spectroscopy. The sputter rates for pure nickel and iron and their alloys have been determined and are independent (within 10%) of the grain size and film composition. The various factors that contribute to the broadening of depth profiles have been examined. The initial broadening of 4.5 nm at zero overlayer thickness is mainly attributed to the effects of electron escape depth and

compositional mixing due to ion bombardment. For thin films, the depth-dependent broadening induced by sputter damage has an approximately exponential dependence on the overlayer thickness. For thick films, this broadening is estimated to be about 10% of the sputter distance. The effect of ion-induced surface compositional mixing as a function of incident Ar^+ ion energy has been studied by taking advantage of the different sampling depths of low and high energy Auger electrons.

Characterization of Electron Traps in Aluminum-Implanted SiO_2 *by D. R. Young, D. J. DiMaria, W. R. Hunter, and C. M. Serrano, p. 285.* Johnson, Johnson, and Lampert have studied the effect of Al implantation on the trapping behavior of SiO_2. The large fluence that they used (1×10^{14} Al/cm^2) and the low annealing temperatures (up to 600°C) resulted in a trapping efficiency of 1 and made it impossible to characterize the traps. In the present study a lower fluence and higher annealing temperatures to reduce the trapping efficiency are used to permit characterization of the traps. The predominant trap cross sections are 1.26×10^{-16} and 1.40×10^{-17} cm^2. In a companion paper by DiMaria, Young, Hunter, and Serrano the location of the trapped charge is discussed.

Location of Trapped Charge in Aluminum-Implanted SiO_2 *by D. J. DiMaria, D. R. Young, W. R. Hunter, and C. M. Serrano, p. 289.* The position of the centroid of electrons trapped on sites resulting from aluminum implantation into SiO_2 is measured by using the photo *I-V* technique for energies from 15–40 keV, oxide thicknesses from 49–140 nm, and post-implant annealing temperatures from 600–1050°C in N_2 for 30 min. The centroid of the trapped electrons is found to be identical to that of the implanted aluminum from SIMS measurements, regardless of annealing temperature from 600 to 1050°C, and located closer (by less than 9 nm) to the Al-SiO_2 interface than predicted from the Lindhard-Scharff-Schøtt (LSS) calculations of Gibbons, Johnson, and Mylroie. Comparison of centroids determined from photo *I-V* and SIMS measurements as a function of SiO_2 thickness also implies that the distributions of the ions and negative trapped charge are the same. The trapping behavior of these sites is discussed in the accompanying paper by Young et al.

X-Ray Photoelectron Spectroscopy of SiO_2-Si Interfacial Regions: Ultrathin Oxide Films *by S. I. Raider and R. Flitsch, p. 294.* The composition and width of the interfacial region formed between thin thermally-grown oxide films and single-crystal Si substrates were nondestructively characterized by means of x-ray photoelectron spectroscopy. Data obtained from variations in core-level binding energies, from variations in photoelectron line intensities, and from variations in photoelectron linewidths indicate the presence of a nonstoichiometric oxide-Si transition region. The composition and width of this region are dependent upon substrate orientation, but are invariant with change in other oxidation processing parameters. Transition regions formed on <100> oriented substrates are narrower and more completely oxidized than those formed on <111> oriented substrates. Although both Si-Si bonds and SiO-Si groups are present in this nonstoichiometric region, they do not appear to be a mixture of Si and SiO_2. Instead, a continuous distribution of Si tetrahedra, $Si\text{-}(O)_x(Si)_{4-x}$, are formed, in which x changes from 0 to 4 as one proceeds from the substrate to the stoichiometric SiO_2 film.

Electronic Properties of (100) Surfaces of GaSb and InAs and Their Alloys with GaAs *by R. Ludeke, p. 304.* Smooth, monocrystalline (100) surfaces of the alloys $In_{1-x}Ga_xAs$ and $GaSb_{1-y}As_y$ were prepared by molecular beam epitaxy. Both As-stabilized c(2 × 8) and metal-stabilized c(8 × 2) surface reconstructions were observed for $In_{1-x}Ga_xAs$ over the entire alloy range. $GaSb_{1-y}As_y$ exhibited a c(2 × 6) or (2 × 3) structure for *y ltequiv* 0.2, and, after a transition region, the anion-stabilized c(2 × 8) or the Ga-stabilized c(8 × 2) structures for *y gtequiv* 0.5. Electron energy loss spectroscopy revealed the simultaneous presence of two empty, dangling-bond derived surface states in both alloy systems. For $In_{1-x}Ga_xAs$ the In-derived empty surface state lies ≈0.4 – 0.5 eV below that of Ga and moves from above the conduction band edge into the band gap for *x gtequiv* 0.6. The overlap between the Ga-and In-derived empty surface states causes the quenching of the Ga(3d) surface exciton. For $GaSb_{1-y}As_y$ the Sb dangling bonds generate an empty, localized surface state which lies 0.2 – 0.3 eV above the empty, Ga-derived surface state. Both levels lie above the conduction band edge throughout the alloy range.

Oriented Epitaxial Films of (NMP) (TCNQ) *by E. E. Simonyi, J. F. Graczyk, and J. B. Torrance, p. 315.* An important step in the characterization of organic conductors is the ability to correlate the solid state electrical properties of these materials with their composition and crystal structure. In many cases it has not been possible to grow single crystals of suitable size or purity for such investigations. The use of epitaxial films represents an alternative approach. In addition, such films may be potentially useful as larger area conductive surfaces. This paper describes the preparation of relatively large-area, oriented epitaxial films of the organic conductor N-methylphenazinium- 7,7,8,8-tetracyanoquinodimethanide (NMP) (TCNQ) by means of vacuum evaporation. Factors that appear to affect the degree of orientation, the film areas, and the chemical composition include the source temperature, the kind of evaporation (rapid or slow), the degree of lattice matching between the substrate and the organic material, and the substrate surface charge potential.

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Low Cost Silicon for Solar Energy Conversion Applications *by G. H. Schwuttke, T. F. Ciszek, K. H. Yang, and A. Kran, p. 335.* Economically viable means of producing silicon solar cells for the conversion of solar energy into

electric power are discussed. Emphasis is given to the discussion of crystal growth techniques capable of growing single-crystal silicon ribbons directly and inexpensively from molten silicon. The capillary action shaping technique (CAST) recently developed by IBM has a good potential for producing low cost silicon sheets suitable for solar cells. This technique has produced ribbon 100 mm wide and 0.3 mm thick. Problems that CAST must overcome in order to supply material for low cost solar cells are discussed. Economic and technological computer-modeled comparisons indicate that continuously grown CAST ribbons of these dimensions can meet a cost objective below $50/m^2 of sheet material. The results require that it be possible to fabricate a twelve-percent-efficient solar cell from CAST ribbon 100 mm wide and 0.3 mm thick at a polycrystalline silicon cost of $10/kg.

Growth of Polycrystalline GaAs for Solar Cell Applications *by A. E. Blakeslee and S. M. Vernon, p. 346.* Films of polycrystalline GaAs have been grown on foreign substrates by the metal-organic process. The main objective was to produce films with as large a grain size as possible, so that high-efficiency photovoltaic devices may eventually be fabricated from such thin film/substrate structures. At 973 K the average grain size was less than 1 μm, and was unaffected by the choice of substrate. Increasing the deposition temperature to 1123 K, while maintaining all other conditions the same, resulted in grains as large as 10 to 20 μm in diameter. Grain sizes as large as 10 μm could be obtained by precoating the substrates with thin films of evaporated gold or tin. However, both of these methods gave films that were discontinuous. A two-step procedure in which the films were nucleated at 873 K prior to growth at 1123 K yielded continuous films with an average grain size of 5 μm. Schottky barrier solar cells fabricated from these films exhibited short-circuit current densities as high as 15.7 mA/cm^2, even though the highest conversion efficiency (AM0, uncoated) was only 1.3 percent because of the low fill factor (0.28).

Organic Photovoltaic Materials: Squarylium and Cyanine-TCNQ Dyes *by V. Y. Merritt, p. 353.* The photovoltaic properties of Schottky barrier sandwich cells consisting of sublimed and solution-cast thin films of selected squarylium (bis-anilino derivatives of cyclobuta-1,3-diene-2,4-dione) and cyanine-tetracyanoquinodimethanide (TCNQ) dyes have been measured. For hydroxy squarylium (OHSq), maximum power conversion efficiencies (η) were 0.2% for 850-nm light (1 mW/cm^2); 0.05% for 633-nm light (94 mW/cm^2); 0.06% for "white" light (21 mW/cm^2); 0.15% for low intensity (0.14 mW/cm^2) simulated AM0 light (sunlight under outer space conditions), and 0.02% for high intensity (140 mW/cm^2) AM0 light. Efficiencies of selected OHSq cells were observed to increase fivefold when the cells were doped with bromine or 1-phenyl-3-p-N, N-diethylaminostyryl-5-p-N,N-diethylaminophenyl-Δ^2-pyrazoline (DEASP), e.g., 0.05 to 0.23% (Br); 0.004 to 0.021% (DEASP). The efficiency of a solution-cast cell of amorphous 2,2'-dicarbocyanine-TCNQ was 0.02% when 933-nm light (approximately (1 mW/cm^2) was used. Amorphous solid solutions of 1,1'-diethyl-2,2'-dicarbocyanine-and oxa-2,2'-dicarbocyanine-TCNQ salts were also tested. The effects of various material and device properties on the performance of organic photovoltaic cells are discussed, and it is proposed that organic solar cells having efficiencies of one percent or more can be made by using existing technologies.

Solar Absorbing Surfaces of Anodized Dendritic Tungsten *by G. D. Pettit, J. J. Cuomo, T. H. DiStefano, and J. M. Woodall, p. 372.* Anodization of textured tungsten is shown to have merit either in creating a solar absorber of extremely high absorptance when applied to a large dendritic surface, or in enhancing the solar absorptance-to-emittance ratio when applied to smaller hillock topographies. The angular dependence of the absorption is reduced by the anodization coating, which consists of a thin conformal coating of WO_3. The surface is stable up to temperatures of 520 K in air.

Optimization Applied to the Design of an Energy-Efficient Building *by S. A. Jurovics, p. 378.* There are several public domain, and numerous proprietary, computer programs that provide detailed simulations of the heating and cooling requirements for a building. Such programs are often used to evaluate changes in the design of a building that are made to decrease its energy requirements. A user is considered to be working in a trial-and-error mode if each execution of the program provides no formal guidance for the next change. This work reports on an investigation of the imbedding of such an energy analysis program into an optimization structure. Such an arrangement would enable a user to specify a set of architectural and construction parameters and the limits within which they might vary, and from this to determine the parameters that yield a local minimum in thermal load and the sensitivity of this load to changes in these parameters.

Color Composite Pictures from Principal Axis Components of Multispectral Scanner Data *by T. Kaneko, p. 386.* When principal axis transformations are applied to multispectral scanner (MSS) data, the majority of data variability is shown to be contained in the first two or three components. This paper describes a method for generating a color composite picture from these components whereby most of the information collected by an MSS can be conveyed in a single color picture. The first component is found to be a weighted sum of image data from all channels, and therefore it is natural to associate the first component with brightness. To be consistent with this interpretation, only the first component of the transformed data is used to control the brightness of the color composite picture.

General Technique for Communications Protocol Validation *by C. H. West, p. 393.* A technique for the validation of protocols in communications systems is described. It can be used for systems composed of processes that can be modeled as finite directed graphs. The validation exhaustively exercises the interaction domain of a system and identifies all occurrences of a number of well-defined error conditions. The method can detect when individual processes have no predefined response to incoming messages, as well as system deadlocks and potential loss of messages due to overflow conditions.

Adaptive Variation of the Transfer Unit in a Storage Hierarchy *by P. A. Franaszek and B. T. Bennett, p. 405.* Consider a paged storage hierarchy with at least two levels L_1 and L_2, where L_1 denotes main storage and L_2 secondary storage. Suppose that the unit of replacement for L_1 is a single page, and that the L_2-to-L_1 transfer unit, given a page fault, is an integer number of pages. Then, given a suitable replacement policy for L_1, increasing the unit of transfer often results in a lower miss ratio at the expense of increased paging traffic. This paper explores the possibility of adaptively varying the L_2-to-L_1 transfer unit as a function of the reference history of the data to be fetched. Experiments on traces drawn from two large data base systems suggest that such adaptation can result in improved tradeoffs between miss ratios and paging traffic.

A Machine-Independent APL Interpreter *by M. Alfonseca and M. L. Tavera, p. 413.* The problem of writing machine-independent APL interpreters is solved by means of a systems programming approach making use of an intermediate level language specially designed for that purpose. This paper describes the language, as well as the procedure used to build universal interpreters. Three compliers that translate this language for three different machines have been written so far, and an APL interpreter has been finished.

Regression Model for LPE Film Property Control *by S. J. Lewis, p. 422.* Empirical regression equations permit the calculation of liquid phase epitaxial (LPE) film properties from film growth parameters. Numerical differentiation of these equations facilitates examination of the sensitivities of film properties to fluctuations in growth conditions and the development of depletion-compensating growth strategies. Regression equations for nominal 3-μm bubble size CaGe and Ga films have been generated and used for quantitative comparisons of the growth behavior of the two systems. A real time feedback control scheme has been applied to the Ga system resulting in 70 percent of the as-grown films falling within ±1 percent of the target collapse field.

Representation for Complex Numbers *by W. N. Holmes, p. 429.* This communication suggests the feasibility of a single-component scheme for representing complex numbers with real bases. Several advantages are pointed out, including the very simple extraction of the real and imaginary parts of a complex number.

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Preface *by L. M. Branscomb.*

Principal Components of a Multispectral Image: Application to a Geological Problem *by A. Santisteban and L. Muñoz, p. 444.* The principal components of a multispectral image are studied with special emphasis placed on photointerpretation applications. The method used to obtain these components involves a linear radiometric enhancement which avoids artifact creation and does not require extra computational work. The results have been particularized to Landsat multispectral scanner images and applied to the geological study of a sedimentary basin in central Spain.

Machine Processing of Remotely Sensed Data: Three Applications in Mexico *by M. Hernández V. and A. Flores M., p. 455.* In general, ground-data acquisition procedures in developing countries are not very efficient, and the resulting lack of reliable data produces significant delays in important management-planning decisions. This paper describes three studies involving different applications of machine processing of remotely sensed data, a recent technology that appears to have potential use for timely ground-information acquisition. The general methodology describes the use of a special software processing system. Finally, some conclusions are presented relating to the specific problems discussed and to the advantages of remote sensing in general.

Using a Desk-Top Computer for an On-Line Flood Warning System *by E. Todini, p. 464.* The paper deals with the development of an adaptive model that is applicable to real-time forecasting of hydrologic processes. The rainfall-runoff process is considered here. In this model the discharge was modeled as autoregressive with past discharges and a moving average representation on the precipitation. The model makes use of the Constrained Linear Systems (CLS) technique to split the precipitation into two rainfall inputs by using a threshold based on an antecedent precipitation index. This technique can be thought of as a piecewise linearization of a nonlinear process. The real-time forecasting model is a time invariant linear state model where the state variables, discharge and rainfall, are estimated by the Kalman filtering algorithm and the unknown model parameters by using the instrumental variables approach. This technique was applied in a case study using data from the Ombrone River Basin, Italy, and was implemented on a small desk-top computer.

Hydrodynamic Numeric Modeling of the Lagoon of Venice *by P. Sguazzero, C. Chignoli, R. Rabagliati, and G. Volpi, p. 472.* This paper describes two hydrodynamic numeric models and their application to the Lagoon of Venice, Italy. The models are based on the same mesh, bottom topography, boundary conditions, and spatial distribution of the bottom

friction coefficient (Chézy coefficient). Although quite different in structure, both models ultimately provide sea level fluctuation and current speed at each meshpoint as functions of time. The first model numerically integrates the time-dependent, nonlinear, hyperbolic shallow water equations, written in conservation form, with a space-staggered leapfrog-type (time dense) scheme. The model is suited to episode simulation and is a particularly useful tool for system management and control. The second model is suited to long-term simulations and models only the astronomic tide; it solves a hybrid (differential-algebraic) system resulting from semilinearization of the shallow water equations under harmonic assumptions for the tide. Because of the superior computational efficiency of this second model, it has been used in conjunction with Powell's algorithm to identify the *a priori* unknown spatial distribution of the Chézy parameter. If the same Chézy distribution is fed into the two models, there can be obtained a complete, self-calibrating, consistent modeling tool for tidal basins with arbitrary geometric configurations and boundary conditions in the presence of hydraulic works.

Extrapolation of Seismic Waveforms by Fourier Methods *by J. Gazdag, p. 481.* The problem of constructing a cross section of reflectivity from the wave field recorded at the surface of the medium is discussed with particular reference to migration of seismic records. The numerical procedures are formulated in the frequency and wavenumber domain. The operations are defined in a fixed coordinate system, whereas finite difference methods require a downward-moving reference frame. The numerical algorithms in the frequency wavenumber domain are simpler and give more accurate results than finite difference methods. This is particularly true when the lateral velocity variation in the medium can oe neglected. In this case the downward wave extrapolation is accomplished by implementing a phase change in the Fourier coefficients. Numerically, this is equivalent to the multiplication by a complex number of unit modulus. There is no stability condition associated with this operation. This means that the source and recorder positions can be lowered by any amount within one computational step.

A Directed Weather Data Filter *by D. W. Low, p. 487.* It is important to reduce the computational burden of energy-analysis computer programs (such as those that compute expected heating and cooling loads and the energy required to meet these loads) since the input may include, for example, hourly measurements of several weather variables over periods of time of up to ten years. It is possible to generate a small set of weather data to represent a larger, more comprehensive set by using computer programs called weather data filters. However, existing filters that are generally able to preserve statistical properties of the original data offer no *a priori* method for controlling or even estimating the errors they introduce in the output of the energy analysis programs. This problem exists because these filters deal only with weather data and do not utilize any information regarding the building to be analyzed, its occupancy schedule, its mechanical systems, or the energy analysis function itself. This paper describes a weather filter that preserves the "energy content" of the data; i.e., given a particular building design and usage schedule, this filter generates a small set of weather data which, when properly weighted, produces the same total heating and cooling loads as the original data. Because the error caused by using the filtered weather data falls well within acceptable bounds even when changes are made in the building design, the filter described allows the designer to test a large number of design or retrofit alternatives for energy efficiency at very low computational cost.

An Analytic Model of the VM/370 System *by Y. Bard, p. 498.* This paper describes an analytic model of an interactive multiprogrammed computer system. The model accepts a multiple-user-class, transaction-oriented workload description and a system configuration description, and it produces predictions of resource utilizations, transaction rates, and average transaction response times. The solution method involves nearly complete decomposition, with a closed queuing network representing the multiprogrammed set. Asymptotic formulas are used to generate good initial guesses for an overall iterative scheme. Extensive validation results are presented.

Algorithm and Hardware for a Merge Sort Using Multiple Processors *by S. J. P. Todd, p. 509.* An algorithm is described that allows log (n) processors to sort n records in just over $2n$ write cycles, together with suitable hardware to support the algorithm. The algorithm is a parallel version of the straight merge sort. The passes of the merge sort are run overlapped, with each pass supported by a separate processor. The intermediate files of a serial merge sort are replaced by first-in first-out queues. The processors and queues may be implemented in conventional solid logic technology or in bubble technology. A hybrid technology is also appropriate.

Computer-Aided Diagnosis with an Application to Endocrinology *by W. Schild, B. Lunenfeld, and B. Gavish, p. 518.* An interactive system for computer-assisted medical diagnosis is described. Medical experts are provided with a framework in which to translate the knowledge on which their decisions are based. The technique is based on simulating the physician's own diagnostic process. The approach taken allows consistency and completeness checks to be made, thereby achieving a high degree of reliability. Information related to a given specialty is described in terms of disorder patterns, clinical facts, and logical relationships among the clinical data. Laboratory results are processed by a subsystem which uses physician-supplied rules to establish validity and to interpret the test data with respect to their diagnostic significance. The system incorporates a dynamically generated questionnaire which provides efficient gathering of anamnestic, observational, and other clinical parameters. The physician is prompted for relevant patient data by an algorithm which assures that an almost minimal amount of

information is requested. Simulation facilities allow the user to examine clustering phenomena among disorders, and an option is included that traces the logic of any decision taken to exclude candidates for a final diagnosis.

Noun-Phrase Model and Natural Query Language *by M. Sibuya, T. Fujisaki, and Y. Takao, p. 533.* Basic considerations in designing a natural data base query language system are discussed. The notion of the noun-phrase data model is elaborated, and its role in making a query system suitable for general use is stressed. An experimental query system, Yachimata, embodying the concept, is described.

AQL: A Problem-solving Query Language for Relational Data Bases *by F. Antonacci, P. Dell'Orco, V. N. Spadavecchia, and A. Turtur, p. 541.* AQL is a query language based on a data base management system which uses Codd's relational model of data. It has been designed mainly to be used by the nonspecialist in data processing for interactive problem solving, application building, and simulation. Ease of use is achieved by providing an interface which allows the use of default options, synonyms, and definitions of attributes, inference, and the possibility of interactive completion of the query (i.e., menu). AQL combines the capabilities of the relational model of data with the powerful computational facilities and control structure of the host programming language (i.e., APL). A prototype version of AQL, which has been implemented, is reviewed.

Interpretation of Natural Language in an Information System *by H. Lehmann, p. 560.* This paper discusses some of the linguistic problems encountered during the development of the User Specialty Languages (USL) system, an information system that accepts a subset of German or English as input for query, analysis, and updating of data. The system is regarded as a model for portions of natural language that are relevant to interactions with a data base. The model provides insight into the functioning of language and the linguistic behavior of users who must communicate with a machine in order to obtain information. The aim of application independence made it necessary to approach many problems from a different angle than in most comparable systems. Rather than a full treatment of the linguistic capacity of the system, details of phenomena such as time handling, coordination, quantification, and possessive pronouns are presented. The solutions that have been implemented are described, and open questions are pointed out.

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AC Gas Discharge Panels: Some General Considerations *by A. Reisman and K. C. Park, p. 589.* This introductory paper attempts to provide some perspective on the key technology issues associated with ac gas panel displays to set the stage for a series of nine technology and physics-oriented papers that follow. It uses the cathode ray tube as a reference for comparison and defines some of the unique technological features of matrix-addressed displays generally and ac gas discharge panels specifically.

Single-Cycle Gas Panel Assembly *by A. Reisman, M. Berkenblit, and S. A. Chan, p. 596.* A single-cycle process has been developed in which the two halves of a gas panel are assembled, sealed, and filled in a continuous, automatically sequenced, controlled-ambient furnace. The entire fabrication operation, including seal, degas, backfill, and tip-off, may be accomplished in a single thermal cycle. During heat-up, the panel parts and furnace chamber are degassed in a programmed cyclic fill (to 20 mm of Hg) and pump-down to (100 μm of Hg). The panels are sealed in a clean-air ambient at a temperature of 495 ± 5°C. Prior to backfilling with a purified Penning gas mixture and tip-off of the panel, the same gas is used in a cyclic fill and evacuate process to remove air and other contaminants. The entire panel fabrication program takes about 8 hours. Details of equipment construction and operation are presented, as well as advantages of the process compared to conventional gas panel fabrication processes.

Obtaining Gas Panel Metallization Patterns by Vacuum Deposition Through Rib-supported Mask Structures *by R. Hammer, p. 601.* Gas discharge display panel metallization patterns have been obtained directly in a single vacuum deposition step through rib-supported mask structures. This approach provides a simple alternative to screening or photoetching. The rib-supported structures were developed to solve problems of fabricating masks containing long and narrow closely spaced apertures, poorly supported cantilever sections, and free-standing islands. The design of these structures minimizes shadowing from support ribs by using non-line-of-sight deposition techniques. Made out of graphite to avoid chemical attack during cleaning operations and fabricated by air abrasion machining, the self-supported masks are held in intimate mask-to-substrate contact during vacuum deposition by an electrostatic hold-down technique.

E-Beam Evaporated Glass and MgO Layers for Gas Panel Fabrication *by K. C. Park and E. J. Weitzman, p. 607.* An electron-beam evaporation process has been developed that is capable of depositing stable, thick, borosilicate glass films (0.5 – 50 μm) on various substrates at a rate exceeding 0.5 μm/min. A very low stress of $4 - 10 \times 10^7$ N/m^2 in compression was obtained in freshly deposited glass films, and a further reduction below measurable levels of stress was observed after a thermal annealing at 500°C. The effects of evaporation parameter variation and thermal annealing on the film properties of the borosilicate glass layers, as well as the MgO secondary emission layers employed in the fabrication of gas discharge display panels, are presented.

Electrical and Optical Characteristics of Evaporable-Glass-Dielectric AC Gas Display Panels *by J. F. O'Hanlon, K. C. Park, A. Reisman, R. Havreluk, and J. G. Cahill, p. 613.* This paper presents the characteristics of a prototype gas display panel fabricated with electron-beam

deposited dielectric films. It is shown that panels with a 6-μm-thick dielectric layer and a 0.2-μm-thick MgO layer exhibit short stabilization times (15 min), long life (20,000 h), small drift effects (<0.5 V), and adequate brightness (21 cd/m^2). The devices have a large dynamic write margin (>10 V) over a wide pressure range. Dielectric glass layers as thin as 3.2 μm were found to be stable. A panel with a small H_2O impurity concentration was used to show that the hydrated MgO surface caused charge leakage and loss of memory margin, while a panel with an air leak confirmed that the surface saturated before the effects of gas contamination were observed.

Effect of Reactive Gas Dopants on the MgO Surface in AC Plasma Display Panels *by W. E. Ahearn and O. Sahni, p. 622.* Experimental results are presented for the influence of controlled levels of important reactive impurities (N_2, O_2, H_2O, CO_2) on the aging characteristics of the operating voltages of ac plasma display panels. Details are also given of a novel method of modifying the electronic properties of MgO surfaces by discharge processing in an oxygen-doped Ne-0.1% Ar Penning mixture.

A Phenomenological Study of AC Gas Panels Fabricated with Vacuum-Deposited Dielectric Layers *by J. F. O'Hanlon, p. 626.* This paper presents the results of an experimental investigation of ac gas display panel parameters. The ignition and extinction voltages were measured for panels filled with Ne-0.1% Ar gas to pressures ranging from 0.75×10^4 Pa to 8×10^4 Pa (50 torr to 600 torr). The panels were constructed with chamber spacings, d, of 0.56×10^{-2} cm to 2×10^{-2} cm, and electrode widths, x, of 1.5×10^{-3} cm to 0.1 cm. Scaling of the Paschen minimum was not found to hold for the narrowest chamber spacing. The dependence of ignition voltage on linewidth was found to be proportional to $\exp(-1.6\,x/d)$ for $(x/d) < 1$. An electron diffusion process was invoked to explain this behavior.

Characterization of Voltage and Charge Transfer in AC Gas Discharge Displays *by E. S. Schlig and G. R. Stilwell, Jr., p. 634.* New techniques have been applied to the characterization of voltage and charge transfer in ac gas discharge display cells. This paper presents a new method of measuring the voltage transfer curve and several aspects of the operation of the cells which are revealed by these measurements. In the steady sustain region the voltage transfer is nearly equal to the initial gas voltage. Over most of the voltage transfer curve, the voltage transferred is independent of the history and operating environment of the test cell. On the other hand, the charge transfer does depend upon these factors. The voltage and charge transferred vary differently with the initial gas voltage, so the effective wall capacitance depends upon the initial wall voltage as well as on history and environment. This is attributed to the dependence of the lateral spread of the discharge upon its strength.

Numerical Calculation of the Characteristics of an Isolated AC Gas Discharge Display Panel Cell *by C. Lanza and O. Sahni, p. 641.* Device characteristics calculated from a one-dimensional dynamic simulation, incorporating space charge effects, of the gaseous discharge occurring at an isolated cell of an ac gas discharge panel are presented. The theoretical model shows all the qualitative features associated with plasma panels, and the quantitative agreement with experimental data inspires confidence in the general validity of the method.

Al-Cu Alloy for Gas Panels *by V. Brusic, F. M. d'Heurle, R. D. MacInnes, E. I. Alessandrini, J. Angilello, J. J. Dempsey, and M. Sampogna, p. 647.* The composition, phase formation, stress, resistivity, and, in particular, the oxidation and corrosion behavior of Cu-Al films with a variety of Cu:Al ratios have been determined. Their relevance to the gas panel is discussed.

Contact Stress and Wear Study for Type Characters *by F. I. Chow, P. A. Engel, D. C. Heath, and S. Lawphongpanich, p. 658.* To ensure the structural integrity of solid print characters subjected to millions of stress cycles, the contact stresses encountered in service must be known. In the present paper various type geometries are explored for their influence on stress distribution. A linear programming method of stress analysis is adopted. Experimental analysis and wear characteristics are considered.

Mechanism of Wear by Ribbon and Paper *by R. G. Bayer, p. 668.* While wear by materials such as ribbon and paper represents a significant and identifiable problem in the business machine industry, it has received little attention in the wear literature. In this paper the results of a study into the nature of the wear processes involved and the various factors which influence them are presented. A significant result of that study is the conclusion that the basic wear processes for both materials are similar, i.e., abrasion by small hard particles as compared to an adhesive mechanism for paper as proposed by some in the literature.

Work-hardening of Ferrite Head Surfaces by Wear with Flexible Recording Media *by R. W. Polleys, p. 675.* The ferrite surfaces of rotating magnetic heads were found to have been work-hardened to different degrees depending upon the abrasiveness of the flexible recording media used. For the more abrasive tape, the work-hardening was less than for the less abrasive tape. Associated with the increase in microhardness was decreased signal read-back and increased incidence of surface "pull-outs." These phenomena may be understood in the context of fracture mechanics where residual stress, resulting from plastic deformation of the ferrite, is predominant in the wear mechanism.

Electroplated Diamond-Composite Coatings for Abrasive Wear Resistance *by D. D. Roshon, p. 681.* This paper

describes electroplated diamond-composite coatings which are capable of attaining wear resistance a number of orders of magnitude greater than conventional materials when subjected to abrasion by paper. The coatings consist of a single layer of diamond particles held in a matrix of electroplated metal. During the course of these studies, many parameters were found to play important roles in the wear resistance. These parameters include the diamond particle size, its size distribution, the particle density, particle shape, plating uniformity, and the properties of the matrix metal. The influence of these variables is discussed, and the results of the wear testing are presented. The plating process is also briefly described.

Calculations of the Effect of Emitter Compensation on β and f_T of Bipolar Devices *by A. Phillips, Jr., p. 687.*
Significant increases in bipolar device β and f_T are predicted when emitter compensation is reduced. The prediction was made after accurately calculating all room temperature device parameters with a bipolar device program. The use of empirical concentration-dependent energy gap values allowed the accurate device calculation.

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Preface *by S. S. Husson, p. 2.*

Electrical Properties of RF Sputtering systems *by J. H. Keller and W. B. Pennebaker, p. 3.* A theory is developed that gives a relatively complete electrical characterization of rf sputtering systems. Three types of systems are analyzed: tuned substrate, driven substrate, and controlled area ratio of electrode (CARE) systems. The theory is applicable to any of these systems that do not use magnetic fields to confine the plasma. Given the input rf power and voltage at the target, and any other parameters that can be specified as independent variables (e.g., pressure, substrate drive voltage, tuning impedance, and system geometry), the theory provides explicit values for all dc and rf electrical parameters of the system. The dc bias developed at the substrate is explained and related to the resputtering energy. In addition, an approximate calculation is presented for the ion density in the plasma; this calculation allows a semiquantitative estimate of the rf voltage developed at the target for a given value of rf input power. It also shows the influence of pressure and frequency on rf sputtering system operation. Comparisons are made with real rf sputtering systems; these show that the theory is quite successful in predicting the operation of these systems. In addition, a much better understanding is achieved of some of the complex electrical phenomena encountered in these systems. The theory should prove useful both for new system design and for diagnostic work on existing equipment.

Influence of Scattering and Ionization on RF Impedance in Glow Discharge Sheaths *by W. B. Pennebaker, p. 16.* The effects of scattering and ionization on the rf impedance of a glow discharge sheath are calculated using an equivalent dc sheath model. The effects of scattering are treated in terms of a drag force; equilibrium between the ion drift velocity and field is not required. The ratio of first ionization coefficient to pressure, α/p, is assumed to be constant, and the ion energy and ion current injected from the glow are assumed as initial parameters. In the limit of low pressures, the calculation agrees with the Child-Langmuir law. At intermediate pressures, the results agree with the mobility limited solution. At high pressures, the product of pressure and sheath dimension, *pd*, becomes constant because of ionization effects. The results of this calculation, obtained by numeric integration, can be accurately approximated by an interpolation formula. This formula provides a simple means for calculating the rf impedance of a sheath.

Sputtering Process Model of Deposition Rate *by J. H. Keller and R. G. Simmons, p. 24.* A model of the sputtering process has been developed that predicts the deposition rate of a sputtering system with parallel-plate geometry. By using data for sputtering yield vs voltage obtained from an ion-beam sputtering system, the model applies a new theory for computing the backscatter of the sputtered material, and, from the results, predicts deposition rates. The model also considers the effects of charge exchange in the sheaths, and of re-emission of sputtered material at the substrate. The model is valid for magnetic, tuned substrate, driven substrate, and controlled area ratio diode systems. Comparison with observed deposition rates shows good agreement for clean systems. An experimental APL program that uses the model has been written.

Some Chemical Aspects of the Fluorocarbon Plasma Etching of Silicon and Its Compounds *by J. W. Coburn and E. Kay, p. 33.* Mass spectrometric sampling of fluorocarbon glow discharges and *in situ* measurements of the etch rate of Si and SiO_2 with quartz crystal microbalances have been used to provide additional insight concerning the chemistry involved when additive gases such as O_2, H_2, N_2, H_2O, and C_2F_4 are injected into a CF_4 glow discharge. The results obtained in our low-pressure, long-residence-time system indicate that the etching behavior of the discharge is not significantly influenced by the molecular structure of the injected gas molecules but is determined primarily by the elemental composition of the glow discharge. This phenomenologically observed result can be used to predict qualitatively the relative etching behavior of a large class of gaseous etchant mixtures as well as the role of various electrode or wall materials in the plasma etching process. Although this oversimplified interpretation should not be extended to short-residence-time plasma systems, it is believed to be valid for some of the configurations used in plasma etching and reactive ion etching.

Photochemical Decomposition Mechanisms for AZ-Type Photoresists *by J. Pacansky and J. R. Lyerla, p. 42.* The photochemical decomposition mechanism of orthonaphthoquinonediazides has been investigated principally by infrared and carbon-13 nuclear magnetic resonance spectroscopies. The results demonstrate that the decomposition proceeds via a ketene intermediate to a photoproduct, the nature of which depends on the reaction conditions. Model resist systems were prepared by mixing orthonaphthoquinonediazides and 2,3,6-trimethylphenol or the diazide plus Novolak resin. Under ambient thermal and humidity conditions, ultraviolet (UV) exposure of the diazide yields 3-indenecarboxylic acid as the final photoproduct. However, UV exposure in vacuo results in ester formation via a ketene-phenolic OH reaction. The decomposition pathway and ensuing reactions have been shown to be the same for both 1- and 3-orthonaphthoquinonediazides attached to mono- and trihydroxybenzophenones. The technological implications for resist processing derived from these studies are also discussed.

Annealing of Poly(ethylene terephthalate)-Film-Based Magnetic Recording Media for Improved Dimensional Stability *by B. F. Blumentritt, p. 56.* PET-film-based magnetic recording media are subject to a number of dimensional instabilities, a major one being in-plane shrinkage due to stress relaxation in the biaxially oriented substrate. Annealing the

media allows stress relaxation without significantly degrading other properties and makes possible the use of higher track densities. Effects of annealing on mechanical properties, coefficients of thermal and hygroscopic expansion, and long-term dimensional stability of the media are described.

Laminated Films with Isotropic In-Plane Properties *by B. F. Blumentritt, p. 66.* Commercially available polymer films used in structural applications, such as biaxially oriented poly(ethylene terephthalate), exhibit pronounced anisotropy in mechanical properties, thermal expansion, and long-term dimensional stability. Films with more nearly isotropic in-plane properties have been produced by laminating plies of PET film at various angles to one another. In addition, composite films have been made with nearly isotropic properties and with significantly reduced coefficients of expansion compared to those of commercially available polymer films. A laminate with PET faces bonded to a low expansion alloy foil core had the best dimensional stability and the least anisotropy of the films studied.

On Future-Dependent Block Coding for Input-Restricted Channels *by P. A. Franaszek, p. 75.* Consider a restricted channel whose constraints may be characterized by a finite state machine model. Conventional coding techniques for such channels result in codes where the choice of a word to be transmitted is only a function of the current state and the information to be represented by this word. This paper develops techniques for constructing codes where the code word choice may also depend on future information to be transmitted. It is shown that such future-dependent codes exist for channels and coding rates where no conventional code may be constructed.

Algorithm to Check Network States for Deadlock *by V. Ahuja, p. 82.* The problem of checking the states of a system for deadlock is treated for a single class of systems, or networks, and for a single class of resources, or buffers. An algorithm is described that, for a given state, requires $O[m + n^2]$ operations, where m and n are, respectively, the number of tasks and nodes in the state. (In general, m is greater than n.)

Break-Up of a Liquid Jet: Second Perturbation Solution for One-Dimensional Cosserat Theory *by D. B. Bogy, p. 87.* The second perturbation solution is derived within the nonlinear one-dimensional Cosserat theory for a liquid jet emanating from a nozzle with harmonic excitation. Numerical results are presented for parameters relevant to ink-jet printing technology. Satellite drops are predicted but always in the backward merging condition. The results are compared with the corresponding solution obtained by Pimbley and Lee, who used a different one-dimensional set of equations with a different formulation of the problem and obtained forward merging satellite drops under some conditions.

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HeNe Parallel Plate Laser Development *by D. A. Chance, J.-C. A. Chastang, V. S. Crawford, R. E. Horstmann, and R. O. Lussow, p. 108.* A parallel plate format is used for fabricating "hard" sealed HeNe lasers. The new packaging geometry and construction process are suitable for large scale manufacturing. Cut plate, molded plate, and folded beam lasers have been built and tested. Several changes from conventional lasers, such as evaporated film cathode and anode, square cross section bore, glass sealed Brewster windows, and "soft" glass bore materials, are discussed. The power output capability, measurements of gain and loss parameters, and the reliability of these lasers are also considered.

Cathodes for HeNe Lasers *by D. A. Chance, V. Brusic, V. S. Crawford, and R. D. MacInnes, p. 119.* Vapor deposited aluminum cathodes for parallel plate HeNe lasers have been used with considerable success. It is shown that the aluminum cold cathode is improved by the addition of copper and that other alloying elements of bulk Al 2024 do not contribute to cathode performance. The plasma oxidation process of Hochuli improves cathode performance by cleaning the surface and optimizing the oxide film for maximum efficiency. There appears to be a trade-off between life and electron tunneling efficiency for optimum oxide thickness. Auger electron spectroscopy, ellipsometry, and scanning electron microscopy are the techniques used for surface characterization.

Nondestructive Analysis for HeNe Lasers *by W. E. Ahearn and R. E. Horstmann, p. 128.* The methods used to measure the gas properties in sealed helium-neon lasers are described. Such parameters as total gas pressure, minor constituent concentration (i.e., He/Ne ratio), and gas purity can be measured using spectral emission methods. How these parameters and measurement techniques relate to the electrical operating characteristics of the laser is described.

Polarization Problems of Parallel Plate Lasers *by J.-C. A. Chastang, p. 132.* Parallel plate laser technology requires that the plasma envelope and particularly the Brewster windows be "hard sealed." The first part of this study reports the effects of misalignments of the Brewster windows on laser performance. This turned out not to be a serious problem. In the second part the increase in the birefringence of the Brewster windows resulting from the hard seal technique is examined. We found that this problem, which is serious, can be eliminated by careful control of the temperature during sealing and the annealing process.

Reduction of Storage Fragmentation On Direct Access Devices *by P. A. Franaszek and J. P. Considine, p. 140.* A technique is described for partially reorganizing the contents of disk storage so as to reduce the level of fragmentation. The method entails choosing that fraction of the contents

which is estimated to have the greatest impact on the free space distribution, followed by the relocation of these data to more favorable locations, subject to the system integrity requirements.

Arithmetic Coding *by J. Rissanen and G. G. Langdon, Jr., p. 149.* The earlier introduced arithmetic coding idea has been generalized to a very broad and flexible coding technique which includes virtually all known variable rate noiseless coding techniques as special cases. An outstanding feature of this technique is that alphabet extensions are not required. A complete decodability analysis is given. The relationship of arithmetic coding to other known nonblock codes is illuminated.

High-Speed Programmable Logic Array Adders *by A. Weinberger, p. 163.* Programmable Logic Array (PLA) adders are described which perform an addition in one cycle with a single pass through a PLA and require a reasonable number of product terms for an 8-, 16-, or even a 32-bit adder. The PLA features two- bit input decoders feeding an AND array followed by an OR array whose outputs are pairwise EXCLUSIVE-ORed. Carry-look-ahead adder equations, adapted to the PLA to require relatively few product terms, are adjusted for maximum sharing of product terms. The number of unique product terms is a relative measure of one of the physical dimensions of the PLA. Equations for contiguous sum bits are grouped into strings, each using a common input carry. A procedure optimally assigns sum bits to strings to further minimize the total number of unique product terms. The methods are extended to PLAs with decoders of increased inputs and substantially reduced product terms. They can serve as dedicated macro functions on a chip, using special decoders relevant to adders. As a result, the other PLA dimension comprising the number of outputs from all input decoders increases only moderately, and can even decrease, with larger decoders. Finally, the PLA adder can be further substantially compressed by splitting the OR array into two parts such that a row of the AND array is shared between two product terms, and an OR array column is shared between two sums of product terms.

Thermal Stress in Bonded Joints *by W. T. Chen and C. W. Nelson, p. 179.* This paper considers the stress distributions in bonded materials induced by differential expansion or contraction of these materials. The analytical approach is similar to the lap joint theories attributed to Volkersen and expanded by Goland and Reissner. Several simple and typical analytical models are presented to bring out the relative importance of different geometrical and material parameters and to give some insight into different modes in which the bonds might fail.

Implications of a Selective Acknowledgment Scheme on Satellite Performance *by M. A. Reed and T. D. Smetanka, p. 189.* Data link response time is becoming more of a concern today with the onset of satellite transmissions of computer data. The long propagation delay inherent to satellite communications may lead to a degradation in data link response time as compared to the same transmission over purely terrestrial links. Furthermore, data link errors need be considered in any such study of response time of satellite data links. A model has been developed to study data link response time under a selective acknowledgment retransmission protocol. The model not only calculates mean link response time, but also the second moment of the response time. This model is then applied to various interactive data transmission schemes over a half-duplex (HDX) satellite link with terrestrial tails, although modifications can easily be made to analyze pure terrestrial or satellite links. The model parameters include bit error rate (*BER*), terrestrial as well as satellite propagation delay, modem transit delay, *MAXOUT* (maximum number of unacknowledged data frames), frame size (bits), and message size (bits).

Study of Head-Tape Interaction in High Speed Rotating Head Recording *by H. J. Greenberg, p. 197.* The steady state tape dynamics resulting from the interaction of a high speed rotating head and a flexible recording tape are formulated within the framework of linear shell theory. Tape displacements in the area above the head are coupled with the solution to the Reynolds equation in order to calculate the film thickness (flying height) between head and tape. Simulated results for spherical heads are compared to observed behavior on experimental systems.

Rapid and Precise Method for Analysis of Energy Dispersive X-Ray Spectra *by T. C. Huang, p. 206.* A new, precise, and rapid method for the analysis of energy dispersive x-ray spectra generated by electron beam or x-ray excitation is presented. It includes the use of Gaussian profiles and a polynomial of $1/E$ (where E is the x-ray energy) to represent the observed x-ray characteristic lines and background, automatic sectioning of the entire spectrum, and a figure of merit to estimate goodness of fit. Details of the method and its programming techniques are given. Results of analyzing complicated energy dispersive x-ray (EDX) spectra of multi-element alloys are presented.

Contrast Attenuation Factors for Remote Sensing *by J. V. Dave, p. 214.* Attenuation factors for the contrast of objects lying on the earth's surface and observed through five different atmospheric models are calculated as a function of the wavelength (0.31-0.9935 μm), solar zenith angle, ground reflectivity, and the nadir and azimuth angles of view. The first model is free of aerosols and absorbing gases. Absorption by average amounts of oxygen, ozone, and water vapor is included in the remaining four models. The second model is also free of aerosols, but the last three models contain aerosols in the form of a spherical polydispersion made from a substance with a spectrally independent refractive index of 1.5-0.01 i. Models 3 and 4 are expected to represent, respectively, the average and strong turbid

conditions encountered over large continental areas. Models 3 and 5 contain aerosols with different size distribution characteristics, but have the same amount of aerosol mass loading per unit horizontal area. The contrast attenuation factor is found to increase with an increase in wavelength and reflectivity of the surrounding surface, and a decrease in the atmospheric turbidity and gaseous attenuation. It also depicts strong azimuthal dependence especially for models illuminated by low-altitude solar radiation of longer wavelengths.

On the Application of Coding Theory to Hashing *by N. Pippenger, p. 225.* Quick proofs are given for the characterization (due to Schay, Raver, Hanan, and Palermo) of the collision distance of a linear hashing function and for a dual notion (called the restriction distance), which relates to the accessibility of addresses by sets of keys and the uniform distribution of sets of keys over addresses.

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Simulation of a Moving Bed Gasifier for a Western Coal *by R. Stillman, p. 240.* This paper describes an adiabatic steady state plug flow model for a moving bed coal gasifier with gas-solid heat transfer. The model considers 17 solid stream components, 10 gas stream components and 17 reactions. The kinetic and thermodynamic parameters were derived for a Wyoming subbituminous coal. Examples of calculated results are given.

The Analysis and Comparison of Actual to Predicted Collector Array Performances *by W. H. McCumber and M. W. Weston, p. 253.* The Hottel-Whillier-Bliss (HWB) equation has been the standard tool for the evaluation of collector thermal performance for four decades. This paper presents a technique that applies the criteria of ASHRAE Standard 93-77 to the determination of the HWB equation coefficients from field-derived data. Results of the analysis of a sample collector array illustrate the technique. Actual dynamic performances of various collector arrays in the field are compared to those predicted by the steady-state efficiency models for the individual panels. In certain cases, the HWB model produces deviations of over 100% from measured hourly performances and 35% from measured monthly performances when compared with the single-panel laboratory-derived model. However, when the field-derived HWB model is used as the basis of comparison the performance deviations were typically less than 5%.

Solar-Grade Silicon by Directional Solidification in Carbon Crucibles *by T. F. Ciszek, G. H. Schwuttke, and K. H. Yang, p. 270.* Directional solidification of silicon in carbon crucibles was achieved by using two variations of the Bridgman-Stockbarger method. One was a static technique wherein liquid silicon in a carbon crucible was positioned in a temperature gradient of about 35°C/cm, with the highest temperature at the top of the crucible. Solidification was achieved by lowering the system temperature at a rate of 4–5°C/min. The second technique entailed lowering a silicon-loaded carbon crucible through a fixed-rf coil at a rate of 0.55 cm/min. Crack-free silicon was produced by both methods. The equilibrium grain structure was initiated by nucleation at the crucible walls, with surviving grains tending to grow in alignment with the temperature gradient to produce an axially columnar grain structure of mainly <110> orientation. The average grain diameter was 0.11 cm; a typical length was 0.7 cm. Solar cells made with this material gave an AM1 conversion efficiency of 11.5%.

Encapsulation of Radioactive Noble Gas Waste in Amorphous Alloy *by J. A. Van Vechten, R. J. Gambino, and J. J. Cuomo, p. 278.* Public demand for the containment and safe storage of radioactive waste materials has caused the U.S. Government to require that, beginning in January 1983, most of the ^{85}Kr, which until now has been vented to the atmosphere during the reprocessing of nuclear fission fuel rods, will have to be captured and retained for several decades. The cost of accomplishing this with present compressed-gas technology is enough to increase the cost of nuclear generated electricity by an estimated 0.3%. However, materials developed for amorphous magnetic bubble memory devices have been found to be capable of storing large quantities of Kr (30 atomic percent) with great stability up to temperatures above 1070 K. The cost of ^{85}Kr storage in the magnetic bubble memory material appears to be less than 1% of that for present compressed-gas technology.

An Access Specification Language for a Relational Data Base System *by R. A. Lorie and J. F. Nilsson, p. 286.* We address the problem of executing high level language queries submitted to a relational data base system. As a step in the process of constructing an "efficient" compiler for a high level language we suggest the elaboration of an intermediate level language acting as a target language for the optimizer part of the compiler. This language may be conceived as one of several levels in a chain of abstract machines mapping a nonprocedural relational language onto primitive data base access operations. It is our conjecture that the introduction of an access specification language provides a conceptual platform facilitating the handling of the "optimization" problem.

Transform Techniques for Error Control Codes *by R. E. Blahut, p. 299.* By using the theory of finite field Fourier transforms, the subject of error control codes is described in a language familiar to the field of signal processing. The many important uses of spectral techniques in error control are summarized. Many classes of linear codes are given a spectral interpretation and some new codes are described. Several alternative encoder/decoder schemes are described by frequency domain reasoning. In particular, an errors-and-erasures decoder for a BCH code is exhibited which has virtually no additional computations over an errors-only decoder. Techniques for decoding BCH, RS, and

alternant codes (Goppa codes) a short distance beyond the designed distance are discussed. Also, a modification to the definition of a BCH code is described which reduces the decoder complexity without changing the code's rate or minimum distance.

Electrodes with Covalently Attached Monolayers *by A. F. Diaz and K. K. Kanazawa, p. 316.* We have used cyclic and second-harmonic ac voltammetry to study solution and solid state electrochemical reactions on metal oxide surfaces chemically modified with silyl derivatives of the type $SnO_2/Si(CH_2)_3NH(CH_2)_xNR_1R_2$. The R groups studied include pyrazoline derivatives, tetrathiafulvalene, and ferrocene. Electrode effects on solution redox reactions involving phenothiazine and benzoquinone have also been compared using both platinum electrodes and the chemically modified electrodes. The results from the various approaches used consistently indicate that the redox reactions are slower on modified as opposed to unmodified electrode surfaces.

On the Zigzag Form of Charged Domain Walls *by M. J. Freiser, p. 330.* Unusual domain walls have been found in ferrofluid patterns on thin film materials with low magnetization that is in or near the plane of the film. These walls carry a net magnetic charge and are characteristically kinked in a regular manner to form a zigzag. A simple account is given of the energetics of such walls whose form follows from a compromise between magnetostatic terms and the energy of anisotropy. It is argued that an array of closure domains at straight edges in these materials should have a boundary of similar character, and these too have been observed.

Probabilistic PERT *by A. Nádas, p. 339.* A solution is offered to the problem of determining a probability distribution for the length of the longest path from source (start) to sink (finish) in an arbitrary PERT network (directed acyclic graph), as well as determining associated probabilities that the various paths are critical ("bottleneck probabilities"). It is assumed that the durations of delays encountered at a node are random variables having known but arbitrary probability distributions with finite expected values. The solution offered is, in a certain sense, a worst-case bound over all possible joint distributions of delays for given marginal distributions for delays. This research was motivated by the engineering problem of the timing analysis of computer hardware logic block graphs where randomness in circuit delay is associated with manufacturing variations. The probability distribution of the critical pathlength turns out to be a solution of an unconstrained minimization problem, which can be recast as a convex programming problem with linear constraints. The probability that a given path is critical turns out to be the Lagrange multiplier associated with the constraint determined by the path. The discrete version of the problem can be solved numerically by means of various parametric linear programming formulations, in particular by one which is efficiently solved by Fulkerson's network flow algorithm for project cost curves.

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Guest Editorial *by P. A. Engel, p. 360.*

Air Film System for Handling Semiconductor Wafers *by J. A. Paivanas and J. K. Hassan, p. 361.* In an automated fabrication facility, the thin, fragile silicon wafers in which semiconductor circuits are formed must be transported to and from processing stations with a minimum of contact with other solid objects so as to minimize damage, contamination, and consequent lowering of product yield. This task has been undertaken for some time now, in IBM and elsewhere, by systems based on a lubricating film of air as a means for levitating and moving wafers. However, due to inherent motion instabilities and specific control needs, some solid contact is typically involved in effecting prescribed wafer motion. The need for solid contact control is greatly reduced by the air film system described in this paper. It is based on a surface configuration that combines two fluid mechanics phenomena to generate a supporting air film that provides and guides wafer motion. Wafer transportation and positioning are achieved with the air film operating in conjunction with special control device techniques.

Micromechanical Membrane Switches on Silicon *by K. E. Petersen, p. 376.* A new class of electronic devices, micromechanical membrane switches, has been developed. These switches have operating characteristics that fill the gap between conventional silicon transistors and mechanical electromagnetic relays. Although they are batch fabricated on silicon using conventional photolithographic and integrated circuit processing techniques, their unique properties allow them to perform functions not ordinarily associated with silicon. The devices are basically extremely small, electrostatically controlled mechanical relays, typically less than 100 μm long. Their high off- to on-state impedance ratio and all-metal conduction paths make them ideally suited for ac signal switching arrays. This paper describes the design, fabrication, operating behavior, and potential applications of these voltage-controlled, micromechanical switches.

An Application of Beam Dynamics to a Damper Design *by H. C. Lee and J. W. Raider, p. 386.* Flexural wave propagation may be used as a means of absorbing impact energy to prevent excessive rebound or to shorten the cycle time of high-speed printing devices. For optimal damping action, however, the dynamic analysis of beams used in the mechanism is necessary; this paper presents such an analysis. It also presents an application of a damper ring design that is used to prevent so-called "shadow printing" by suppressing the rebound of the type elements in a disk printer.

Interposer for Disk Printer *by J. H. Meier and J. W. Raider, p. 392.* In an impact printer which selects characters by

having a hammer hit type elements as they travel at constant velocity past the print location, a significant design problem results from the requirement that the hammer hit only the selected character. In the usual configuration this requirement limits printing speed because the hammer penetrates the plane of the moving type elements and spends a sufficient time in this plane to risk collision with an adjacent type element. This paper describes, for printers with widely separated hammers, a technique to effectively eliminate the "in-plane" time. A cammed interposer is used to transfer most of the kinetic energy of the hammer to the type element, with the remaining energy being absorbed in strain energy of the interposer. For one printer, this technique resulted in an increase in the printing speed from 15 to 30 characters per second.

A Cylindrical Print Element System for a Serial Impact Printer *by J. Zable, p. 396.* For an impact serial printer, like a typewriter terminal, it is desirable to print fast and to print with a minimum of maintenance. For printing to take place, the carrier containing the print element must be in the correct position along the print line and the character selection must be made by the proper positioning of the print element. This paper discusses a cylindrical thin-walled print element containing an entire character array on its outside surface. The print element is rotated and translated independently by two prime movers (motors). The cylindrical print element geometry and the prime movers are optimized to minimize the time required for character selection. Surface area, stress, inertia, torque, and motor requirements are considered. Selection times and printing rates are computed for simulated printing conditions.

Dynamic Response of a Print Belt System *by P. A. Engel, H. C. Lee, and J. L. Zable, p. 403.* The dynamic response of a print belt system, when the print belt is subjected to impulsive print forces, is analyzed in this paper. The system consists of a flat steel print belt tightly wrapped around pulleys with one of the pulleys driven by a motor. Analytical modeling allows the prediction and analysis of belt motion and thus the prediction of print misregistration. Discrete parameters used in the analysis permit simulation of the belt motion as affected by variations in belt tension, stiffness, pulley inertias, and motor-operating parameters. Conditions of belt slippage are examined, as well as the effect of dynamic loading upon the drive motor.

Harmonic-Drive Ribbon Stuffer for Impact Printers *by E. F. Helinski, p. 411.* This paper describes a harmonic-motion ribbon-stuffing device for impact printers, which maintains a consistent placement pattern for large-capacity (120 yards) endless-loop fabric ribbons. The ribbon is uniformly placed into a cavity by eccentric drive rolls that ensure alternate ribbon switching due to the geometric relationship of drive rolls and strippers. The ribbon is positively placed in a manner much like a fixed-displacement drive, thus differing significantly from the principle used by existing ribbon packers, which achieve ribbon placement by balancing the difference in net driving force against the buckling resistance of the ribbon.

Document Scanner Mechanism *by W. D. Clark, p. 415.* A document scanner mechanism, developed for use in a conventional copier having mirrors which scan a document and reflect the image onto a rotating photoconductor drum, is described in this paper. The engineering design and operation of the mechanism are presented, and the development of an analytical model for simulating its operational characteristics is described, together with the results and conclusions of the simulation. A novel means of generating the scan motion and the important design considerations leading to the development of the scanner mechanism are also presented.

Planning and Execution of Straight Line Manipulator Trajectories *by R. H. Taylor, p. 424.* Recently developed manipulator control languages typically specify motions as sequences of points through which a tool affixed to the end of the manipulator is to pass. The effectiveness of such motion specification formalisms is greatly increased if the tool moves in a straight line between the user-specified points. This paper describes two methods for achieving such straight line motions. The first method is a refinement of one developed in 1974 by R. Paul. Intermediate points are interpolated along the Cartesian straight line path at regular intervals during the motion, and the manipulator's kinematic equations are solved to produce the corresponding intermediate joint parameter values. The path interpolation functions developed here offer several advantages, including less computational cost and improved motion characteristics. The second method uses a motion planning phase to precompute enough intermediate points so that the manipulator may be driven by interpolation of joint parameter values while keeping the tool on an approximately straight line path. This technique allows a substantial reduction in real time computation and permits problems arising from degenerate joint alignments to be handled more easily. The planning is done by an efficient recursive algorithm which generates only enough intermediate points to guarantee that the tool's deviation from a straight line path stays within prespecified error bounds.

A Numerical and Experimental Study of the Bistable-Unstable Transition in Pressurized Flexible Disk Files *by D. B. Bogy, J. E. Fromm, and F. E. Talke, p. 437.* The bistable operating region of flexible disk files is limited at decreasing air flow rates by a transition at which undesirable gaps appear in the otherwise uniformly spaced disks of the pack. These spontaneous gaps, as opposed to the externally controlled gaps of the bistable range, are a consequence of local air flow fields at the outer edge of the disks. Experiments with external shrouds of various clearance showed axial periodicity in the occurrence of the gaps and provided physical insight which led to quantitative numerical solution of the nonlinear fluid equations. Two scales of the flow, i.e., the flow between individual disks and a peripheral

unstable Couette flow, are found to couple in such a manner as to delineate the transition.

Experimental Determination of Creep Functions for Thin Orthotropic Polymer Films *by D. B. Bogy, N. Bugdayci, and F. E. Talke, p. 450.* Stringent requirements on the dimensional stability of polymer films used as substrates for magnetic recording make it necessary to experimentally determine their anisotropic viscoelastic behavior. This paper deals with the measurement of the time-dependent, longitudinal elongation and lateral contraction of 50 × 900-mm biaxially oriented orthotropic polyethylene terephthalate (PET) strips. Two different methods are described for measuring longitudinal elongation, and a laser-scanning technique is used for measuring lateral contraction. Preliminary investigations are carried out to determine the static Poisson's ratio, to check the linearity of longitudinal creep with respect to load, and to investigate the validity of the time-temperature superposition hypothesis. In addition, tests are described in which longitudinal and lateral creep of the specimens are simultaneously measured under constant loads in temperature- and humidity-controlled environments. It is found that the Poisson's ratio has only a weak dependence on time, and, therefore, a good approximation may be obtained by treating the Poisson's ratio as independent of time.

Tunnels in Semiconductor Epitaxy *by J. C. Marinace, p. 459.* On (100) surfaces of III-V or II-VI compounds, tunnels or grooves can be grown over oxide or Mo stripes, the axes of which are in one of the two orthogonal <110> directions on the surface. One <110> direction produces grooves and the other, tunnels. By switching from *n*- to *p*-type layers at frequent intervals during growth, the mechanism can be elucidated.

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Contributions of IBM to Laser Science—1960 to the Present *by P. P. Sorokin, p. 476.* IBM's role in the discovery of new lasers and in the development of their scientific potential is described. A brief survey is presented of laser-related projects conducted within IBM's Research Division laboratories at Yorktown Heights, NY, San Jose, CA, and Zurich, Switzerland.

Systematic Behavior in Alkaline Earth Spectra: A Multichannel Quantum Defect Analysis *by J. J. Wynne and J. A. Armstrong, p. 490.* "Two-electron" atoms are more complex than "one-electron" atoms because of electron-electron interactions. This leads to spectra that are not well understood. Using multiple photon excitation and ionization detection, we have extensively tudied Rydberg series of states in Ca, Sr, and Ba. The spectroscopic data were interpreted by using multichannel quantum defect theory (MQDT). In this context, systematic trends in the atom series Ca, Sr, and Ba are discussed.

Two-Photon Coherent Transients *by M. M. T. Loy, p. 504.* Two-photon nutation, free-induction decay, and population inversion by adiabatic rapid passage have been studied in NH_3. These effects are easily visualized with a vector model. Relaxation time T_1 and T_2 have been measured.

Cooperative Emission of an Excited Monolayer into Surface Plasmons *by H. Morawitz, p. 517.* The cooperative emission of an excited molecular monolayer into surface plasmons of a metallic substrate is described. The effect arises from the very strong coupling of an electronically excited molecule to surface plasmons at distances that are short compared to the wavelength of the electronic transition. Strong resonant enhancement of this excited molecule-surface plasmon interaction occurs for near-degeneracy of the electronic transition frequency and the asymptotic surface plasmon frequency $\omega_p/2^{1/2}$. It is shown theoretically how the two-dimensional analogue of superradiance can arise, leading to a highly directional and very intense surface plasmon pulse. This pulse or series of pulses has soliton-like characteristics and may be expected to propagate for considerably longer distances along the metal-vacuum interface than do individual surface plasmons.

Subnanosecond Optical Free-Induction Decay *by R. G. DeVoe and R. G. Brewer, p. 527.* A novel form of laser frequency switching is devised that extends coherent optical transient studies to a 100-picosecond time scale, the measurements being performed in real time. Free-induction decay (FID) on a subnanosecond time scale reveals new features, such as a first-order FID that dephases with the inhomogeneous dephasing time T_2^* and interferes with the well-known nonlinear FID. A complete analytical expression for optical FID is derived and supports our FID observations for the sodium D_1 transition.

One- and Two-Photon Laser Photochemistry in Organic Solids *by D. M. Burland and D. Haarer, p. 534.* The criteria for site-selective low-temperature laser photochemistry in organic solids are discussed within a general framework that includes both one- and two-photon photochemical reaction schemes. We identify requirements for the use of this photochemistry in photochemical hole burning applications such as high-resolution spectroscopy and the study of low-temperature reaction mechanisms. The one- and two-photon reaction schemes are quite different from one another with respect to excited state geometries and short-lived photoreactive intermediates. The reversible tautomerism of quinizarin in hydrogen-bonded host materials is studied as a one-photon example. The photochemistry involves both intra- and intermolecular hydrogen bonds. The photodissociations of s-tetrazine (ST) and dimethyl-s-tetrazine (DMST) are studied as examples of the two-photon reaction and a kinetic scheme is proposed for the tetrazine case. The intensity dependence of the photochemistry in solids is modeled mathematically.

Photochemical Hole Burning in Free-Base Porphyrin and Chlorin in n-Alkane Matrices *by S. Völker and R. M. Macfarlane, p. 547.* In inhomogeneously broadened lines, selective photochemistry with narrow band lasers leads to photochemical hole burning. We describe this phenomenon with particular reference to free-base porphyrin (H_2P) and chlorin molecules in n-alkane matrices at low temperatures. It is shown that hole burning, which is permanent at low temperatures, can be used to study homogeneous optical dephasing processes as a function of temperature, to measure fast vibronic relaxation, and to assign complex vibronic spectra. Some of the parameters that are important to the potential use of photochemical hole burning for information storage in inhomogeneously broadened lines are measured and discussed.

Time-Resolved Infrared Spectral Photography: A New Technique *by D. S. Bethune, J. R. Lankard, M. M. T. Loy, and P. P. Sorokin, p. 556.* A new technique for photographic or multichannel photoelectric recording of broad band infrared absorption spectra with approximately 5-ns time resolution is described. The technique is based on resonant four-wave mixing in alkali metal vapors.

(GaAl)As Laser Requirements for Local Attached Data Link Applications *by J. D. Crow, p. 576.* The characteristics of (GaAl)As double heterostructure stripe contact injection lasers as they relate to applications in fiber optic data transmission systems are reviewed. The laser characteristics are treated as optical, electrical, thermal, and mechanical interfaces to the system in order to emphasize the necessity of designing devices as a functional part of a system or subsystem. It is concluded that the laser is generally well suited as an optical source in a card-mountable hybrid module transmitter for data links up to a few km and ≈100 Mbit/s data rates. Areas requiring further development include lowering of the laser threshold current, improving the modal stability, packaging the laser with electronics and fiber optic transmission lines, and improving the laser lifetime under varying ambient temperature conditions.

GaAs/(GaAl)As Laser Technology *by R. T. Lynch, Jr., M. B. Small, and R. Y. Hung, p. 585.* This paper is a review of some recent work at IBM on semiconductor injection lasers. An automated system has been built and used for the epitaxial growth of laser material and we describe testing procedures used to characterize this material. Results on the degradation of these lasers at high continuous wave optical power are also presented.

Molecular Beam Laser-Induced Fluorescence Studies of Chemical Reactions *by A. C. Luntz, p. 596.* Crossed molecular beam experiments that use laser-induced fluorescence spectroscopy as the detector allow measurements of the internal state distribution in the products of chemical reactions studied under well-controlled single-collision conditions. This technique provides direct information on the chemical dynamics and the intermolecular potential surfaces. Application to the reactions $H + NO_2 \rightarrow OH + NO$ and $O(^3P) + C_6H_{12} \rightarrow OH + C_6H_{11}$ is discussed where the OH state distribution has been measured.

Forced Rayleigh Scattering *by D. W. Pohl, p. 604.* Forced Rayleigh scattering (FRS) is a light scattering technique used to investigate light-induced grating structures that decay in a relaxational or almost relaxational manner. Such gratings can be created by interference and absorption of two pump beams and probed by a third beam, usually of different frequency. They may consist of spatially varying excited state populations with picosecond lifetimes or of long-lived variations in temperature, composition, and/or density. Forced Rayleigh scattering provides high sensitivity with respect to the amplitude and dynamics of such gratings and allows investigations not accessible by classical scattering techniques. The principles, techniques, and applications of FRS are reviewed.

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Survey of Computer-Aided Electrical Analysis of Integrated Circuit Interconnections *by A. E. Ruehli, p. 626.* In the last decade an important shift has taken place in the design of hardware with the advent of smaller and denser integrated circuits and packages. Analysis techniques are required to ensure the proper electrical functioning of this hardware. In this paper we give a coherent survey of the modeling and computer-aided design techniques applicable to solving these problems. Methods are considered for the computation of resistances, capacitances, and inductances. Also, an extensive list of references is given.

Potential Distribution and Multi-Terminal DC Resistance Computations for LSI Technology *by C. M. Sakkas, p. 640.* Computer time and storage requirements are the two main considerations in the design of a packaging analysis software tool for the problem of calculating the electric potential distribution in arbitrary geometrical shapes. The FEM (Finite Element Method) is the accepted approach for solving such problems. A new formulation for the linear triangular element is presented which is used to derive a very simple and computationally inexpensive linear rectangular element equation interrelating only the geometrical centers of the elements. The result is a much sparser assembly matrix with a maximum of five non-zero entries per equation compared with the usual nine of the FEM formulation. In addition, a method to obtain the minimum bandwidth of the matrix is given for the efficient and static use of external storage, permitting the solution of any size problem. The methods are applicable to multi-plane, multi-terminal configurations for the production of equivalent-resistance networks and for the calculation of the potential distribution throughout the configurations.

Resistive and Inductive Skin Effect in Rectangular Conductors *by W. T. Weeks, L. L.-H. Wu, M. F. McAllister, and A. Singh, p. 652.* A model based on network theory is presented for calculating the frequency-dependent resistance and inductance per unit length matrices for transmission line systems consisting of conductors with rectangular cross sections. The calculated results are compared with actual measurements. Excellent agreement is obtained over a wide range of frequencies, including the mid-range where neither dc values nor high-frequency limit values apply.

Three-Dimensional Inductance Computations with Partial Element Equivalent Circuits *by P. A. Brennan, N. Raver, and A. E. Ruehli, p. 661.* Inductance computations represent an important part in the design of hardware packages, especially for high performance computers. Partial element equivalent circuits (PEEC) are used in this paper to investigate two problems, viz., the inductance of ground plane connections and the reduction in inductance due to eddy currents set up in perpendicular crossing wires. The results from the PEEC models are compared, for the first problem, to experimental hardware measurements and, in the second case, to simplified analytical solutions.

Exploiting Symmetry in Electrical Packaging Analysis *by W. T. Weeks, p. 669.* Many properties of physical systems can be expressed by symmetric matrices of order n, where n is the number of components in the system. The computer storage requirement for inverting the most general symmetric matrix is $n(n+1)/2$ storage locations. For large values of n, the number of multiplications required is proportional to n^3. If the physical system possesses certain geometrical symmetries, both the amount of storage and the number of multiplications can be reduced substantially. It will be shown that if the physical system possesses p orthogonal planes of symmetry, where $p = 1$, 2, or 3, and if n is sufficiently larger, then the storage requirement can be reduced approximately by $1/2^p$ and the number of multiplications by $1/4^p$.

Transient Analysis of Uniform Resistive Transmission Lines in a Homogeneous Medium *by A. J. Gruodis, p. 675.* Transient analysis of resistive transmission lines has always been difficult. The need for this type of analysis, however, did not become critical until high-density circuit packaging became commonplace. This paper discusses a method for the transient analysis of resistive lines. It does not require a large number of equivalent circuit elements, and yet it can be used to represent a resistive line to any desired accuracy.

Geometry Effects of Small MOSFET Devices *by F. H. Gaensslen, p. 682.* The effects of diminishing MOS inversion channel length or width on device characteristics are discussed. As opposed to the geometric device size, an "electric device size" is established by normalizing all dimensions on an appropriately chosen depletion layer width. It is shown how this "electric size" governs the intensity of geometry effects. DC device modeling methods are reviewed with respect to their ease of application to electrically small devices. Finally, means for reduction of geometry effects are considered.

Stability of Lateral pnp Transistors During Accelerated Aging *by S. J. Gillespie, p. 689.* Lateral *pnp* devices stressed under accelerated temperature and voltage conditions show a degradation in the transistor breakdown voltage. These results and additional experiments that were conducted to better understand the mechanisms involved in the observed behavior are described. It was concluded that the degradation can be related to a negative surface charge in the base region of the transistor. This preliminary finding has design and process implications for potential improvement of bipolar device reliability in applications that call for high voltages and low epitaxial doping concentration.

An Elementary Proof of Nonexistence of Isometries between u_p^k and u_q^k *by D. Coppersmith, D. T. Lee, and C.-K. Wong, p. 696.* For $k = 2$, the two-dimensional coordinate spaces u_1^2 and u_∞^2 are isometric. Consequently, results on computational complexity for one space can be transplanted to the other in a natural way. In this note, an elementary proof is given for the nonisometry between u_p^k and u_q^k for general k, p, and q.

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Design of Large ALUs Using Multiple PLA Macros *by M. S. Schmookler, p. 2.* This paper describes methods of designing large Arithmetic and Logical Units (ALUs) using multiple Programmable Logic Array (PLA) macros in which the outputs are obtained in one cycle corresponding to one pass through any PLA. The design is based on the well-known technique of providing conditional sums and group carries in parallel and selecting the proper sum using gating circuits. The PLA for each group of bits uses an adder design published by Weinberger in which each bit of the sum is formed from the EXCLUSIVE-OR of two outputs of the OR array. By placing the gating circuits in front of the EXCLUSIVE-OR circuits, the sums can be obtained using two OR array outputs for each bit and one additional OR array output for each internal string of bits. Also discussed are how ALUs containing more than two groups can obtain the group carries using a separate carry-look-ahead PLA macro and how this macro can be compressed by using special decoders and special physical design layout techniques. Additionally, the paper demonstrates how the PLAs can be used to provide detection of overflow and of zero results, and to also provide Boolean operations.

A Heuristic Test-Pattern Generator for Programmable Logic Arrays *by E. B. Eichelberger and E. Lindbloom, p. 15.* This paper describes a heuristic method for generating test patterns for Programmable Logic Arrays (PLAs). Exploiting the regular structure of PLAs, both random and deterministic test-pattern generation techniques are combined to achieve coverage of crosspoint defects. Patterns to select or deselect product terms are generated through direct inspection of an array; test paths to an observable output are established by successive, rapidly converging assignments of primary input values. Results obtained with a PL/I program implementation of the method are described; these results demonstrate that the method developed is both effective and computationally inexpensive.

Design Automation and the Programmable Logic Array Macro *by R. L. Golden, P. A. Latus, and P. Lowy, p. 23.* The Programmable Logic Array (PLA) macro is a physical structure which simplifies LSI chip design while yielding high density and good performance. In addition, the inherent order and regularity of this structure provide opportunities to speed design through automated logic documentation, design verification by computer simulation, and computer-automated physical design. In this paper a chip design methodology is described which is based on the use of PLA structures (or macros) within a chip. Logic functions in array form are specified in a compact notation that is automatically converted either to array personalization patterns or to conventional logic blocks for input to existing checking and testing software. Simulation of any logic array is performed by a single program subroutine operating on these patterns. In addition, the simple, regular nature of the logic array lends itself to automatic generation of the layout geometries necessary to actually build the array on a silicon chip. Programs developed for these purposes and the PLA macro design procedures are described in the context of an engineering design system.

Error Recovery Scheme for the IBM 3850 Mass Storage System *by A. M. Patel, p. 32.* The IBM 3850 Mass Storage System (MSS) stores digital data on flexible magnetic tape media; however, it is different in many respects from the conventional multitrack tape machines. In particular, the use of a single-element rotary read-write head imposes new demands in the areas of data encoding and error recovery. This paper presents a comprehensive scheme for error recovery for the 3850 MSS which features a new error-correction code in a serial, single-stripe data format. The recovery procedure is designed around resynchronizable sections of data which are rendered independent of each other in error modes through the use of zero-modulation encoding and self-contained error-detection pointers. These error-detection pointers and the resynchronization signals are utilized in conjunction with interleaved codewords of the error-correction code. The code is designed with a generating polynomial in which the roots are chosen from the set of elements of a 16-element subfield of the Galois field GF(2^8). This choice provides the necessary code structure for desired code capabilities and facilitates fast decoding of errors with an economical implementation of the decoder. The scheme provides correction capabilities for various combinations of mixed-mode short and long errors common to magnetic tape recording of digital data.

Synchronous Bounded Delay Coding for Input Restricted Channels *by P. A. Franaszek, p. 43.* Consider the class of input restricted channels whose constraints can be modelled by finite state machines. This paper treats the problem of constructing fixed rate (synchronous) codes for such channels subject to a constraint that the coding delay be bounded by a parameter M. M is the maximum number of information symbols required by the coder in choosing a word during transmission.

Determining Deadlock Exposure for a Class of Store and Forward Communication Networks *by V. Ahuja, p. 49.* Given a network design, is the network exposed to deadlock for message buffers? This problem is addressed for a class of networks called "routed networks." A routed network is a store and forward communication network in which all transmissions follow predefined routes through the network. It is shown that a routed network is exposed to deadlock if and only if there exists a complete weighted matching of an appropriately defined bipartite graph for some subgraph of the network graph. An approach for determining whether a deadlock can occur is presented.

On a Class of One-Step Majority-Logic Decodable Cyclic Codes *by S. Lin and G. Markowsky, p. 56.* Majority-logic decoding is attractive for three reasons: (1) It can be simply

implemented; (2) the decoding delay is short; and (3) its performance, while suboptimal, is always superior to bounded distance decoding. For these reasons, majority-logic decodable cyclic codes are very suitable for error control in high speed digital data transmission systems. Among the majority-logic decodable codes, the one-step decodable codes can be most easily implemented; they employ a single majority-logic gate. In this paper we study a class of one-step majority-logic decodable cyclic codes. First, we describe these codes in a simple manner. Second, a way of finding the orthogonal polynomials for decoding these codes is presented. Third, we show that for a given error correction capability, the ratio of the number of parity digits to the code length goes to zero as the code length increases. For error correction capabilities of the form $2^k - 1$ or 2^k, we determine the dimensions of the codes exactly.

A Geometric Modeling System for Automated Mechanical Assembly *by M. A. Wesley, T. Lozano-Pérez, L. I. Lieberman, M. A. Lavin, and D. D. Grossman, p. 64.* Very high level languages for describing mechanical assembly require a representation of the geometric and physical properties of 3-D objects including parts, tools, and the assembler itself. This paper describes a geometric modeling system that generates a data base in which objects and assemblies are represented by nodes in a graph structure. The edges of the graph represent relationships among objects such as *part-of, attachment, constraint,* and *assembly.* The nodes also store positional relationships between objects and physical properties such as material type. The user designs objects by combining positive and negative parameterized primitive volumes, for example, cubes and cones, which are represented internally as polyhedra. The data base is built by invoking a procedural representation of the primitive volumes, which generates vertex, edge, and surface lists of instances of the volumes. Several applications in the automatic assembly domain have been implemented using the geometric modeling system as a basis.

On the Complexity of Permuting Records in Magnetic Bubble Memory Systems *by K. Chung, F. Luccio, and C.-K. Wong, p. 75.* In this paper we study the problem of permuting records in various simple models of magnetic bubble memories. Previous studies usually assumed the memory system either had one switch or n independently controlled switches, where n is the number of records to be permuted. In the former case, the time complexity to permute a set of n records is $O(n^2)$, while in the latter case, the time complexity is $O(n)$. In this paper, we propose several simple models of bubble memory systems with their numbers of switches ranging between 1 and n and analyze the respective time complexities and respective numbers of control states for some permutation algorithms designed especially for them. Specifically, four models are studied: They have essentially $\log_2 n$, $2\sqrt{n}$, $(\log_2 n - \log_2 \log_2 n)^2$, and k switches; their respective time complexities are essentially $(3/2)n \log_2 n$, $(5/2)n$, $(7/2)n$, and $2^{-1/k}kn^{1+(1/k)}$; and their respective numbers of control states are essentially $4 \log_2 n$, $2^{\sqrt{n}+1}$, $2n/\log_2 n$, and $4k$.

Interferometric Wavelength Measurements through Post-Detection Signal Processing *by R. V. Pole, A. J. Spiekerman, and T. W. Hänsch, p. 85.* Modern electronic signal processing techniques make it possible to use a conventional scanning Fabry-Perot interferometer for highly accurate measurement of (tunable) laser wavelengths. An experimental device is described in which the time intervals between resonances of an unknown wavelength are compared with those of a stabilized He-Ne reference laser by the use of highly accurate electronic timing devices. The accuracy is further enhanced through signal averaging over many scan periods. Accuracies approaching one part in 10^7 are expected to be readily achievable.

Pattern Optimization for UPC Supermarket Scanner *by B. U. Braunecker, p. 89.* Different scanning patterns χ are analyzed in order to determine the degree of redundancy. To this purpose, we evaluate the number of resolution points N_χ which are generated by a sweeping laser beam, while the merchandise is moved across the scanning window. The goal is to find the pattern which minimizes N_χ for an acceptable detection rate.

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Josephson Computer Technology: An IBM Research Project *by W. Anacker, p. 107.* This special issue of the IBM Journal of Research and Development describes the status of IBM's research project on Josephson computer technology. This first paper traces the origins and history of Josephson technology as it led to the project and outlines the project's scope. The potential of the technology for ultrahigh-performance computer mainframes is discussed and the major technological characteristics of LSI Josephson devices are examined. The paper then provides an overview outline of the remaining papers presented in this issue.

Overview of Josephson Technology Logic and Memory *by J. Matisoo, p. 113.* This paper serves as an introduction to the other logic and memory papers in this issue. Basic concepts of superconductivity and electron tunneling underlying the operation of Josephson devices are outlined and an overview of the literature on the subject is presented, with emphasis on work performed at the IBM research laboratories since the beginnings of the Josephson computer technology program in 1965.

Design of 2.5-Micrometer Josephson Current Injection Logic (CIL) *by T. R. Gheewala, p. 130.* This paper describes Josephson Current Injection Logic (CIL) circuits. The design of the basic logic circuits, the two-and four-input OR and AND gates, and a timed inverter circuit, is presented in full detail and the logic delay and its sensitivity to design and fabrication parameters are investigated using detailed models

of devices based on a 2.5-μm technology. The nominal logic delay of the circuits is estimated at 36 ps per gate for an average fan-in of 4.5 and fan-out of 3. The corresponding average power dissipation is 3.4 microwatts per gate. Finally, experimental delay measurements are presented for two-input and four-input OR and AND gates. The delay experiments are in excellent agreement with computer simulations.

Basic Design of a Josephson Technology Cache Memory *by S. M. Faris, W. H. Henkels, E. A. Valsamakis, and H. H. Zappe, p. 143.* Design work on components for Josephson computer technology nondestructive read out cache memories has been published previously. In this paper, presenting a design for a 2.5-μm technology, 4 × 1K-bit cache chip with a nominal access time of about 500 ps as a basis, we show for the first time how these components are structured and interfaced. The cell, drivers, decoder, and a sense bus are based on designs which were experimentally verified in a 5-μm technology for which excellent agreement was found between computer simulations and measurements.

Investigations for a Josephson Computer Main Memory with Single-Flux-Quantum Cells *by P. Guéret, A. Moser, and P. Wolf, p. 155.* The paper first summarizes requirements for a main memory with Josephson junctions and reviews the work carried out on an experimental main memory model containing an array of single-flux-quantum cells, line drivers, and address decoders with a total of nearly 4500 Josephson junctions. In the second part, theoretical and experimental investigations on the y drive system, including sense circuit, are presented. The investigations deal with both the read and write phases. Finally, the on-chip logic circuits and the address decoders are discussed, and the experimental results presented. Drivers and decoders based on the principle of current steering in superconducting loops are intended to be used on a fully populated main-memory chip.

An Overview of Josephson Packaging *by A. V. Brown, p. 167.* An overall packaging philosophy for high-speed Josephson computers is outlined in this paper. The unique characteristics of such a package, operating a liquid helium temperature, are described, and a description is given of the technologies needed to build the package.

The Characteristics of Chip-to-Chip Signal Propagation in a Package Suitable for Superconducting Circuits *by H. C. Jones and D. J. Herrell, p. 172.* We have measured the electrical characteristics of chip-to-chip-carrier connectors ideally suited to high-performance Josephson LSI circuits. Self- and mutual inductances between connectors were measured by incorporating the connectors in a dc SQUID (Superconducting Quantum Interference Device) and confirmed by detailed signal delay and crosstalk measurements made with Josephson logic circuits.

Modeling of Characteristics for Josephson Junctions Having Nonuniform Width or Josephson Current Density *by R. F. Broom, W. Kotyczka, and A. Moser, p. 178.* Several models, both static and dynamic, for calculating the maximum dc Josephson current versus external magnetic field "characteristic" of tunnel junctions of various geometries are described. The static models have the advantage of short computation times; the dynamic models, although slower, yield additional information on circuit-switching times. The dependence of the characteristics on the junction shape is described. The accuracy of a one-dimensional approximation used in the models has been tested experimentally, and theoretically against a two-dimensional approximation. In both cases, the one-dimensional treatment yields quantitatively good agreement provided the inductance of the junction is included in the model. Junctions defined by an oxide "window" of sinusoidal shape (maximum and minimum width at the center and ends, respectively) have a characteristic in which the side lobes are almost completely suppressed. The characteristics of a wide variety of junction shapes, including interferometers having two or more junctions, have been accurately calculated, permitting the design of devices for specific purposes.

An Overview of Materials and Process Aspects of Josephson Integrated Circuit Fabrication *by I. Ames, p. 188.* Presented here is an overview of materials and process aspects of a method that has been developed for fabricating experimental integrated circuits containing Josephson junctions as active elements. Superconducting Pb-alloy thin films are used for forming the junction electrodes, and a combination of thermal and rf oxidation is used for forming the tunnel barrier oxides. In addition to the junctions, the circuits, which are formed above an insulted, superconducting Nb ground plane, also contain: superconducting Pb-alloy lines, contacts, and transformers; $AuIn_2$ damping and terminating resistors; insulated crossings; etc. Insulation between the ground plane and overlying conducting layers is achieved through use of a combination of Nb_2O_5 and SiO. The latter is also used to achieve insulation between overlying conducting layers and as a final protective coating. Photoresist processes are used for layer patterning.

Fabrication Process for Josephson Integrated Circuits *by J. H. Greiner, C. J. Kircher, S. P. Klepner, S. K. Lahiri, A. J. Warnecke, S. Basavaiah, E. T. Yen, J. M. Baker, P. R. Brosious, H.-C. W. Huang, M. Murakami, and I. Ames, p. 195.* A process for fabricating experimental Josephson integrated circuits is described that is based primarily on the use of vacuum-deposited Pb-alloy and SiO films patterned by photoresist stencil lift-off. The process has evolved from one previously reported, with changes having occurred in junction electrodes, tunnel barrier formation, layer patterning, device geometry, and minimum linewidths. Films of Pb-In(12 wt%)-Au(4 wt%) alloy (200-800 nm thick) are used for forming junction base electrodes, interferometer controls, and interconnection lines. Tunnel barriers are formed on the base electrode films by thermal oxidation and subsequent sputter-etching in an rf-oxygen plasma. Junction counter

electrodes are formed from 400-nm-thick Pb-Bi(29 wt%) alloy films. Ground planes are formed from 300-nm-thick Nb films patterned by subtractive etching and insulated in part by a Nb_2O_5 layer formed by liquid anodization. Films of the intermetallic compound $AuIn_2$ (30-43 nm thick) are used for forming terminating, load, and damping resistors. The SiO films are used for interlayer insulation, for defining junction areas in interferometers, and as protective coatings. Layer patterning is achieved mainly by means of photoresist lift-off stencils. By utilizing this process, experimental logic and memory circuits containing ≈100 interferometers with lines as small as 2.5 μm in width have been successfully fabricated.

Effect of Process Variables on Electrical Properties of Pb-Alloy Josephson Junctions *by R. F. Broom, R. Jaggi, T. O. Mohr, and A. Oosenbrug, p. 206.* Our studies on the effect of process variables on the electrical properties of Josephson tunnel junctions were directed toward optimization of the process for cryogenic memory applications, for which special importance is placed on the dc Josephson current density j_1, its stability and reproducibility, and the junction quality. Variables studied included rf voltage, oxygen plasma pressure, the presence of oxygen during deposition of the counter electrode, the composition and surface state of the base electrode, junction geometry, radial position on the wafer, and storage and annealing conditions. Various process adjustments were made in order to obtain acceptable device characteristics. For example, good tunnel characteristics could be obtained using Pb-Au-In alloys if In concentrations >8 wt% (for a fixed 3% Au concentration) were used in the base electrode. High pressure and low rf voltage during oxidation were preferable, since these conditions led to low annealing factors. We were also able to adjust j_1 locally by irradiation with high-energy (>5 keV) electrons.

Fabrication and Properties of Niobium Josephson Tunnel Junctions *by R. F. Broom, R. B. Laibowitz, T. O. Mohr, and W. Walter, p. 212.* The fabrication of thin-film Nb tunnel junctions is described. The main emphasis is on improvement of the tunneling characteristics through studies of the conditions influencing the formation of the tunnel barrier. *In situ* ellipsometric measurements have been made during growth of the tunnel oxide on the base electrode of the junctions in an rf plasma. The results are compared with electrical measurements on completed junctions. Two additional processes are found to have an important influence on the junction characteristics: precleaning of the base electrode in an Ar plasma before oxidation and a further treatment of the grown oxide in a low-voltage, high-pressure plasma. At the present time, the most effective gas for this process is N_2. Data on annealing, storage effects, and thermal cycling are discussed. Finally, the results obtained on arrays of 80 two-junction interferometers are found to be rather encouraging for the design and construction of high-density memory arrays.

Structure of Tunnel Barrier Oxide for Pb-Alloy Josephson Junctions *by J. M. Baker, C. J. Kircher, and J. W. Matthews, p. 223.* The oxide formed on Pb-In and Pb-In-Au alloy films by processes similar to those used to fabricate oxide tunnel barriers for experimental Josephson junction devices has been investigated with transmission electron microscopy and diffraction (TEM/TED), Auger electron and x-ray photoelectron spectroscopies (AES and XPS), and ellipsometry. Thermal oxidation of Pb-In(13 at%) alloys at room temperature results in a noncrystalline oxide, whereas oxides formed at ≥ 60°C in low pressures of O_2 result in a continuous stable epitaxial layer of cubic In_2O_3 ≈2.5 nm thick. The oxide formed by sputtering such a thermal oxide in an rf-excited O_2 glow discharge (rf oxidation) results in a layered structure ≈6.5 nm thick, the bulk of which consists of an upper layer of epitaxial In_2O_3 and a lower layer of crystalline orthorhombic and tetragonal PbO. The thickness of the PbO layer depends on the availability of In at the metal-oxide interface, and thus, on the alloy composition and the temperature and rate of oxidation. For In concentrations above ≈18 at%, the bulk of the oxide was found to be entirely epitaxial In_2O_3. An additional ≈0.3-nm-thick surface layer of PbO is observed, which arises from material sputtered from the Pb-coated rf electrode and subsequently backscattered onto the surface of the oxide. Altering this backscattered material from lead oxide to indium oxide increases the current densities of completed junctions by more than a factor of 40. In contrast, variations in the composition of the lower portions of the oxide have little effect on the junction characteristics. Factors affecting the composition and reproducibility of the oxide are discussed.

Properties of $AuIn_2$ Resistors for Josephson Integrated Circuits *by C. J. Kircher and S. K. Lahiri, p. 235.* The influences of film thickness and composition on the resistivity and microstructure of $AuIn_2$ films, which are used as resistors in Josephson integrated circuits, have been investigated. The films were prepared by evaporating Au and In layers onto SiO-coated Si wafers held at 348 K. The resistivity at 4.2 K was found to be ≈5 μΩ-cm for 40-nm-thick films and to vary as $\approx d^{-0.76}$ over the thickness range 30-250 nm. Corresponding sheet resistances ranged from 0.05 to 2 Ω/□. Resistivity changes were also observed as the composition was altered. A decrease of ≈10% in the In/Au thickness ratio from that of $AuIn_2$ produced an increase of ≈50% in resistivity. A similar increase in In/Au ratio produced ≤ 10% decrease in resistivity. Electron microscopy analysis revealed that the grain size of $AuIn_2$ films increases with film thickness, and is approximately two times smaller for the low In/Au ratio films than for those of nominal or larger In/Au ratios. The factors governing the resistivity of $AuIn_2$ films were analyzed using the Fuchs surface scattering and Mayadas-Shatzkes (M-S) grain boundary scattering theories. It was found that the M-S theory can be used to explain the resistivity data for a range of choices of r and p, the grain-boundary-reflection and surface-reflection coefficients, respectively. Reasonable agreement was obtained for parameter values between

$r = 0.31$, $p = 0$, $\rho l = 3 \times 10^{-11}$ Ω-cm² and $r = 0.74$, $p = 1$, $\rho l = 0.8 \times 10^{-11}$ Ω-cm². The available evidence is interpreted as favoring grain boundary scattering as the dominant scattering mechanism.

JSP—A Research Signal Processor in Josephson Technology *by F. F. Tsui, p. 243.* This paper describes briefly the main architectural and design features of the Josephson Signal Processor (JSP), including its data flow, basic circuit arrangement, and packaging concept. Preliminary partitioning has indicated that, using a 5-μm "single turn logic" technology, the JSP—consisting of about 5000 cells (each with four Josephson junctions) of logic, about 150K bits of nondestructive read out (NDRO) memory, 256K bits of destructive read out (DRO) memory, and 6K bits of read only memory (ROM)—can be packaged in about 20 modules, occupying about 60 cc and consuming about 500 mW of power. The target cycle time for the JSP is 5 ns, with the NDRO and DRO memories having an access/cycle time of about 2.5/4 and 15/30 ns, respectively. Using a 2.5-μm "current injection logic" technology, the JSP—consisting of about 9000 three-junction and 5000 two-junction interferometers—can be packaged in seven modules occupying about 12 cc and will consume about 250 mW of power. The target cycle time for this technology is about 2 ns, with the NDRO and DRO memories having access/cycle times of 0.9/1.4 and 15/30 ns, respectively.

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Preface *by S. S. Husson, p. 267.*

A Silicon and Aluminum Dynamic Memory Technology *by R. A. Larsen, p. 268.* The Silicon and Aluminum Metal Oxide Semiconductor (SAMOS) technology is presented as a high-yield, low-cost process to make one-device-cell random access memories. The characteristics of the process are a multilayer dielectric gate insulator (oxide-nitride), a *p*-type polysilicon field shield, and a doped oxide diffusion source. Added yield-enhancing features are backside ion implant gettering, dual dielectric insulators between metal layers, and circuit redundancy. A family of chips is produced using SAMOS, ranging from 18K bits to 64K bits. System features such as on-chip data registers are designed on some chips. The chip technology is merged with "flip-chip" packaging to provide one-inch-square modules from 72K bits through 512K bits, with typical access times from 90 ns to 300 ns.

Cross-Coupled Charge-Transfer Sense Amplifier and Latch Sense Scheme for High-Density FET Memories *by K. S. Gray, p. 283.* This paper describes a sense scheme for use on high-density one-device cell field effect transistor random access memories (FET RAMs). The high-sensitivity threshold-independent cross-coupled charge-transfer sense amplifier and latch is used. The IBM 64K-bit one-device dynamic memory cell FET RAM chip design is used as the vehicle for the discussion. Adaptations made on the sense amplifier and latch for use with the sense scheme are discussed. Also described are 1) dummy cell design, 2) subthreshold leakage considerations, 3) single-ended input/output (I/O) circuitry sensing and ramifications, 4) multiple cycle signal degradations, and 5) a maximum supply voltage (V_H) buffer circuit sense scheme improvement.

Circuit Implementation of Fusible Redundant Addresses on RAMs for Productivity Enhancement *by B. F. Fitzgerald and E. P. Thoma, p. 291.* This paper describes the circuit schemes used to substitute redundant storage locations for defective ones found during testing. Word or bit lines are added along with appropriate bit steering circuitry to allow the replacement of a defective word or bit line. On-chip storage elements are "set" by the tester and used to store the binary addresses of the failing word or bit lines, which are then compared to the incoming addresses by the redundancy circuitry. This circuitry then activates the replacement word or bit lines and, by various means described, steers out the defective ones. A variation is described briefly which includes a word redundant circuit scheme that provides no penalty in memory access time by using separate sense amplifiers for the redundant lines.

VLSI Device Phenomena in Dynamic Memory and Their Application to Technology Development and Device Design *by R. R. Troutman, p. 299.* Ever-increasing density poses significant challenges to the device designer, who must relate an integrated technology to the numerous electrical characteristics required for successful memory design. Success of a VLSI technology depends as much on the extensive design of small devices as on the sophisticated lithography with which to fabricate them. Several dimensional limitations arise from the electrical characteristics both of intentionally switching devices and of possible parasitic devices. Account must be taken of threshold dependence on both channel length and width. Furthermore, any isolation scheme must not introduce leakage from the storage node, such as parasitic subthreshold and low-level punch-through currents. Hot electron emission depends on both horizontal and vertical dimensions and must be minimized to guarantee the requisite long-term device behavior. This paper will briefly discuss the physical origins of the above fundamental device phenomena, their influence on SAMOS device design, and implications for future memory technologies.

Reduction of Leakage by Implantation Gettering in VLSI Circuits *by H. J. Geipel and W. K. Tice, p. 310.* Damage introduced by ion implantation on the back side of the wafer is used to reduce the MOS transient (relaxation) and junction leakage; the technique is applied to dynamic memory cells. Conditions necessary to ensure efficient gettering by various species (B, Ar, Kr, and Xe) are established based on achieving a sufficient density of **b** = ½<110> dislocations. When the implantation occurs through a screen oxide, dose levels of less than 3×10^{14} ions/cm² for Ar were found to be suitable.

Equivalent leakage reduction was obtained for all species. Specifically, B at 5×10^{15} ions/cm^2 was as effective in reducing relaxation leakage as was 1×10^{15} ions/cm^2 of Ar for the particular thermal history of the investigated process.

A 64K FET Dynamic Random Access Memory: Design Considerations and Description *by T. C. Lo, R. E. Scheuerlein, and R. Tamlyn, p. 318.* The major design considerations and design features of an experimental 64K-bit random access memory (RAM), implemented in a double polysilicon gate technology, are described in this paper. Design tradeoffs addressing power supply selection and chip configuration alternatives are presented. This is followed by a description of the 8K-word by 8-bit FET dynamic RAM which uses single-transistor cells with first-level-metal bit lines and second-level-metal stitched polysilicon word lines. Test results obtained on early engineering hardware chips fabricated with linear dimensions 1.2 times those of the base design are also presented.

A 256K-Bit Charge-Coupled Device Memory *by A. Tzou, Y. Gopalakrishna, E. Blaser, O. Bar-Gadda, and R. Carballo, p. 328.* This paper describes the design of an experimental 256K-bit serial-access memory using VLSI fabrication technology and low-power dynamic circuits. The memory array chip is implemented with a double polysilicon process and uses charge-coupled devices (CCDs) grouped in 64 blocks of 4K bits each. Operation is typically at a 300-ns-per-bit cycle for both read and write modes, with operating voltages of +8.5, +5.0, and −2.2 volts, and with 310 mW of power dissipation. All inputs and outputs, with the exception of a chip enable and two system clock lines, are TTL-level compatible. The unique design features and the organization of the 256K CCD chip are discussed; the array organization, the chip layout, the peripheral circuitry, and the buried-channel CCD device design are described; and test results obtained on experimental hardware are presented.

A One-Device Memory Cell Using a Single Layer of Polysilicon and a Self-Registering Metal-to-Polysilicon Contact *by V. L. Rideout, J. J. Walker, and A. Cramer, p. 339.* The fabrication and operation of a novel one-device dynamic memory cell are described. Like the conventional double overlapping polysilicon cell, the new memory cell has a diffused bit line and a metal word line, uses five basic masking operations, and provides essentially equivalent cell area for the same lithographic feature size. Unlike the double polysilicon cell, however, the new cell uses a single layer of polysilicon to provide a more planar surface topography, and a self-registering metal-to-polysilicon contact to provide a small cell area. An essential aspect of the fabrication method of the self-registered contact cell is the use of two lithographic masking operations that define two patterns in a single polysilicon layer, the MOSFET gate electrode and the MOS capacitor electrode. The self-registering contact also facilitates a powerful polysilicon wiring technique that is applicable to the access circuits located peripherally to the array of memory cells.

Near-Ideal Si-SiO_2 Interfaces *by L. A. Kasprzak and A. K. Gaind, p. 348.* The Si-SiO_2 interface plays a key role in insulated-gate field-effect transistors (IGFETs). Of principal concern are the interface charge density Q_{ic} and the fast-state density N_{fs}. These properties can be optimized by eliminating the transition region and creating an abrupt interface. Our work with the chemical vapor deposition (CVD) of SiO_2 using a CO_2-SiH_4-H_2 system in the presence or absence of trace amounts of HCl gas at 1000°C has demonstrated that unannealed CVD SiO_2 on (100) Si using a vertical-cold-wall reactor has properties similar to those of unannealed SiO_2 on (100) Si formed by the usual thermal oxidation procedure. In addition, using only 2.27 vol% HCl, we have produced films of SiO_2 on (111) Si that are better than their thermal counterparts, unannealed or annealed; i.e., $Q_{ic} \approx 5 \times 10^{10}$ cm^{-2} and $N_{fs} \approx 10^{10}$ cm^{-2}-eV^{-1}. We attribute these results, at least in part, to an abrupt interface between the CVD SiO_2 and Si. Deposition rates of 10-20 nm/min were used to reproducibly deposit 30-50 nm of SiO_2. The CVD SiO_2 films also show a significantly lower standard deviation in the breakdown fields ($\pm$ 1.5%) and the mobile charge densities ($\pm$ 5%) than their thermal counterparts. In general, N_{fs} was independent of Q_{ic}.

Reliability of SiO_2 Gate Dielectric with Semi-Recessed Oxide Isolation *by D. W. Ormond and J. R. Gardiner, p. 353.* This paper reports the results of a study to minimize defects in the gate oxide and in the single crystal substrate of semi-recessed oxide (Semi-ROX) structures. It is shown that both an increase in oxidation mask thickness and a decrease in wet field oxidation temperature markedly reduce the incidence of low voltage breakdown in the gate oxide. Microscopic studies of samples which exhibited low voltage breakdown showed that the Si_3N_4 oxidation mask had failed to protect the surface of the region in which the gate oxide was grown. Semi-ROX processing also exhibited edge breakdown, most likely due to the Kooi effect (nitrided Si surface). The use of a thicker "pad" oxide and a decrease in the wet field oxide thickness were beneficial in reducing the magnitude of degradation in gate breakdown due to this edge effect.

Implanted Source/Drain Junctions for Polysilicon Gate Technologies *by H. J. Geipel and R. B. Shasteen, p. 362.* Shallow (<1.0-μm) n^+-p junctions are required for dense dynamic FET memory. Ion implantation is a natural technology to fulfill the geometric requirements of shallow highly doped n^+ regions in a dual polysilicon gate IGFET technology. However, implantation of ^{31}P and ^{75}As at high dose levels severely damages the crystal lattice and subsequently is difficult to anneal. This tends to make implanted junctions more leaky than their diffused counterparts and causes them to have lower apparent reverse breakdown voltages. The detrimental effect of residual end of process damage, resulting from the implantation, is

correlated to the electrical characteristics of the n^+-p junction. A junction process technology is described that can provide leakage levels of less than 0.25 fA/μm² (25 nA/cm²), sharp reverse *I-V* characteristics, and junction depths of 0.25 to 1.0 μm.

A Contactless Method for High-Sensitivity Measurement of p-n Junction Leakage *by R. L. Verkuil, H. W. Curtis, and M. S. Pak, p. 370.* A contactless *p-n* junction leakage measurement method is described that uses low-noise vhf oscillator circuitry to examine the dynamic memory-like behavior of the junctions. This method utilizes the eddy current loading effect, via inductive coupling, in order to determine the leakage-dependent decay time of the photoinduced voltage across the diffused *p-n* junctions. The contactless measurement is made under low forward bias conditions (≤10 mV) such that this measurement is a function of only generation-recombination processes in the junction depletion region. In the low-noise circuitry, sensitivity is enhanced when the oscillatory amplitude is made directly proportional to the figure of merit *Q* of the coupled oscillator resonant *LC* tank. This simple oscillator circuit contains only one JFET and a small number of inductors and capacitors, and is supplied by a constant-current source. Junction decay times between 10^{-4} and 1 s, corresponding to junction leakages between 10^{-6} and 10^{-10} A/cm², respectively, have been measured and are in excellent agreement with the derived theory showing the contactless decay time to be inversely proportional to the conventional contacting reverse leakage.

1/*N* Circuit and Device Technology *by A. Bhattacharyya, D. P. Gaffney, R. A. Kenyon, P. B. Mollier, J. E. Selleck, and F. W. Wiedman, p. 378.* The 1/*N* memory cell is the bipolar analog of the FET one-device cell. A thin dielectric and doped polysilicon are combined with bipolar technology to achieve a vertically integrated, high-density, fast-performance memory chip. The circuit design, device structure, and processing implementation for a 64K-bit dynamic, 1/*N* fractional-device, experimental bipolar memory are presented. Test results for several geometrical and structural variations, including 16K-bit storage arrays, are given.

A System Solution to the Memory Soft Error Problem *by D. C. Bossen and M. Y. Hsiao, p. 390.* High-density and/or high-performance memory chip designs often create new reliability problems; one good example is the alpha-particle problem for high-density RAM and CCD chips, the problem being that soft errors may "line up" with existing hard errors, giving rise to double errors which are not correctable with conventionally implemented single-error-correcting double-error-detecting codes. In this paper it is shown that an overall system approach based on error-correcting codes and system maintenance strategy will reduce the main memory failure rate at the system level as if the alpha-particle problem had not occurred. This system solution is designed to be compatible with most existing memory designs so that there should be minimal additional cost for implementing it. The procedure described herein uses the capability of a single-error-correcting and double-error-detecting code to detect one hard and one soft error; then a microcode and hardware algorithm performs the correction of both errors. Results of both analytical and simulation modeling of the method and its comparison with other techniques are also included.

Yield Model for Productivity Optimization of VLSI Memory Chips with Redundancy and Partially Good Product *by C. H. Stapper, A. N. McLaren, and M. Dreckmann, p. 398.* A model with mixed Poisson statistics has been developed for calculating the yield for memory chips with redundant lines and for partially good product. The mixing process requires two parameters which are readily obtained from product data. The product is described in the model by critical areas which depend on the circuit's sensitivity to defects, and they can be determined in a systematic way. The process is represented in the model by defect densities and gross yield losses. These are measured with defect monitors independently of product type. This paper shows how the yield for any product can be calculated given the critical areas, defect density, and mixing parameter. Future yields are forecast by using expected improvements in defect densities. Examples show good agreement between actual and calculated yields.

A Charge Injection Transistor Memory Cell *by I. T. Ho, J. Riseman, and H. Greenhaus, p. 410.* In this paper, two versions of an experimental bipolar dynamic memory cell are described. The memory cell consists of one *p*-channel MOSFET and a bipolar *npn* transistor with extensive node sharing. The MOSFET device controls the charge injection into the floating base of the *npn* transistor, and the bipolar device provides amplification for the stored charge during read operation. For memories, this cell offers performance associated with bipolar technology and chip density comparable to MOSFET memories.

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Computer Simulation of Electron-Beam Resist Profiles *by D. F. Kyser and R. Pyle, p. 426.* A user-oriented, conversational computer program, LMS (Lithography Modeling System), has been developed for rapid investigation of the total lithographic process used in electron-beam lithography, including electron exposure and resist development. Electron scattering and energy deposition within the resist film are simulated with Monte Carlo techniques, including the significant effects of electrons backscattered from the substrate. The magnitude of and correction for the resulting intra- and inter-line proximity effects in the latent image and their dependence on variables such as beam voltage, film thickness, substrate material, and line-pattern geometries are easily investigated with LMS. The latent image in the resist film is transformed into a solubility-rate image. The time evolution of the

developed-resist profile and its dependence on electron dose, solvent, etc. can also be determined.

Proximity Effects in Electron Lithography: Magnitude and Correction Techniques *by M. Parikh, p. 438.* Proximity effects due to electron scattering in the resist and substrate seem to set a fundamental limit to the areal density that can be achieved in electron lithography. This work briefly reviews the form and the magnitude of the proximity function and its extent as evidenced by deviations in designed linewidths. It also discusses methods to decrease the proximity effect as well as the algorithms used for correction of such effects.

Single-Step Optical Lift-Off Process *by M. Hatzakis, B. J. Canavello, and J. M. Shaw, p. 452.* A process is described that allows the use of the lift-off metallization technique with ultraviolet exposure of a single layer of ®AZ-type photoresist. The process consists of soaking the resist layer for a predetermined time either in chlorobenzene or other aromatic solvents such as toluene and benzene before or after exposure. After development, resist profiles with overhangs suitable for lift-off metallization are obtained. It appears that removal of solvent and low-molecular-weight resin from the AZ resist may be responsible for the observed differential development rates. In addition, the soak time and temperature behavior indicate a diffusion-type process.

Overlay in Lithography *by H. R. Rottmann, p. 461.* Advances in lithography rely largely on the capability of reducing overlay errors, which in turn depends on the capability to make two-dimensional overlay measurements. This paper describes a simple and accurate method of determining singular overlay errors of step-and-repeat exposure systems with a precision of ± 0.01 μm (standard deviation).

Defect-Related Breakdown and Conduction in SiO_2 *by M. Shatzkes, M. Av-Ron, and R. A. Gdula, p. 469.* A statistical model incorporating the effects of defects provides a good representation of breakdown results for Al-SiO_2-Si MOS capacitors. Implications of this model for interpretation of the yield from life tests and histograms obtained from ramp tests are discussed for the case of a Poisson distribution of defects over the capacitors. The breakdown rates of MOS capacitors in life tests are found to be correlated to defects inferred from conduction measurements.

Stand-Alone Wiring Program for Josephson Logic *by W. E. Donath, p. 480.* This paper describes a channel routing wiring program and its interface to the user. Of particular interest are its interface facilities, which permit manual update of the routing, pre-routing, and incremental routing. A hierarchical organization of the logic is feasible, which permits moving of complex entities, such as latches, adders and others, as complete entities. The internal wiring of these entities could either be done manually and be fixed before layout, which would be desirable when the wiring was used as a delay line, or could be left in the wiring program, which would route them more flexibly. The features above are made possible by the special-interface organization used here. In this interface the pins on the devices can be directly addressed, relatively addressed, and indirectly addressed; a simple macrocompiler permits the hierarchical organization of the data.

Existence of Good δ-Decodable Codes for the Two-User Multiple-Access Adder Channel *by S. Lin, T. Kasami, and S. Yamamura, p. 486.* This paper defines a class of δ-decodable codes for the two-user multiple-access adder channel with binary inputs. This class is a generalization of the class of two-user codes investigated by Kasami and Lin (1978). Lower bounds on the achievable rates of codes in this class are derived. We show that, for a wide range of error correcting capability, this class contains good two-user δ-decodable codes with rates lying above the timesharing line.

Optimal Accelerometer Layouts for Data Recovery in Signature Verification *by J. S. Lew, p. 496.* Current experimental use of pen acceleration data for signature verification has prompted the mathematical theory of our recent paper on the subject, expounding motion recovery techniques for a special pen with imbedded accelerometers. This continuation seeks to optimize the instrument layout as a mechanical filter which serves to extract the kinematic observables from the experimental noise. Our early sections, through various algebraic postulates, determine a simplest function of the layout geometry expressing the relative desirability of an accelerometer configuration. Any nontrivial layout demands some off-axial instruments, but natural "feel" requires few such placements. Hence, our middle sections prove mathematical results under various geometric assumptions which yield optimal layouts with one, two, or three off-axial instruments. Our final sections discuss the further constraint that all accelerometers measure just three directions. They assume not more than two off-axial instruments and obtain the best configurations of these tridirectional types.

Procedures for the Study of the Flexible-Disk to Head Interface *by G. G. Adams, p. 512.* The response of a rotating flexible disk interacting with a read-write head is analyzed. The disk deflection due to an arbitrary distributed normal pressure is coupled with the Reynolds lubrication equation for the disk-to-head air bearing. Procedures which considerably reduce the computation time necessary for obtaining a converged solution are described. A parameter study is then discussed and its results presented.

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Pattern Partitioning for Enhanced Proximity-Effect Corrections in Electron-Beam Lithography *by M. Parikh and D. E. Schreiber, p. 530.* This paper presents new

algorithms for judicious partitioning (or subdivision) of arbitrary lithographic patterns in order to achieve increased quality of proximity-effect correction as well as increased efficiency in the computation of such corrections. Experimental results verifying the correctness of such algorithms are also presented.

Proximity Correction Enhancements for 1-μm Dense Circuits *by W. D. Grobman, A. J. Speth, and T. H. P. Chang, p. 537.* The proximity effect in electron-beam lithography, which is due to electron scattering in the resist and wafer, results in nonuniform exposure and development for patterns in which the incident doses of all the shapes are the same. Correction for this effect has been accomplished in the past primarily by varying the incident doses of all the shapes in order to achieve an equal average resultant dose per unit area for all shapes. We show that in the case of dense circuits with linewidths of about 1 μm or smaller, two enhancements to the proximity correction technique can be easily implemented. One of these is a simple approach to shape breakup (partitioning) to enable dose correction to be applied nonuniformly within the original design shapes. The other technique is a new type of algorithm for forming subsets of the design to perform self-consistent dose correction. These two enhancements are applied to LSI chip data for dense circuits and are shown to permit fabrication of circuits which would be more difficult to process using the proximity correction techniques described previously, due to the particular geometries present in these circuit designs. We also show the application of step and repeat pattern recognition algorithms to compact the resulting data, and consequently to reduce the amount of data by an amount which is greater than the increase in the number of shapes caused by partitioning.

Registration Mark Detection for Electron-Beam Lithography—EL1 System *by D. E. Davis, p. 545.* In electron-beam lithography for the direct exposure of wafers for integrated circuit manufacturing, accurate registration is necessary to achieve the required pattern overlay. This paper examines elements that should be considered to optimize the registration mark detection process in an automatic registration system for an e-beam lithography tool such as IBM's EL1. Included is a section on the generation of the backscatter signals and the proper combination of these signals to reduce the detection uncertainty errors in a system with four backscatter detectors. Signals obtained from resist-coated marks with several vertical profiles are presented for illustration and comparison with the predicted results. Beam shot noise, resist effects, and other factors that affect the signal-to-noise ratio are discussed and some pattern overlay results from EL1 are given.

Electron-Beam Resists for Lift-Off Processing with Potential Application to Josephson Integrated Circuits *by J. H. Magerlein and D. J. Webb, p. 554.* Several electron-beam resists suitable for lift-off processing have been investigated with particular attention to the requirements for fabricating Pb-alloy Josephson integrated circuits. The desired resist must perform well with a baking temperature near 70°C, provide a reproducible undercut edge profile with good linewidth control, and adhere to the necessary substrates. Diazo resists as well as the commonly used PMMA and copolymer materials were studied. Initial results suggest that ®AZ-1350J soaked in chlorobenzene to enhance the undercut profile can satisfy many of these requirements. At present, the amount of undercut obtained is larger than desired, limiting the minimum separation between exposed features to about 1.5 μm.

Estimation of State Probabilities Using the Maximum Entropy Principle *by Y. Bard, p. 563.* A simple method is derived for computing state probabilities of a system when the probabilities of certain aggregate states are known. The method is based on maximizing the system entropy. It is shown that the results obtained by the method satisfy certain assumptions on statistical independence between events. The method is applied to a problem arising in computer performance analysis.

Variance Reduction Techniques for the Simulation of Markov Processes, I: Multiple Estimates *by P. Heidelberger, p. 570.* A method for reducing the variance of simulation-generated estimates is proposed and discussed. The method may be applied to the estimation of steady state parameters of discrete and continuous time Markov chains, semi-Markov processes, and regenerative discrete time Markov processes on a general state space (such as the waiting time process in a multiple-server queue). The method is similar to the technique of control variables, but differs in that the means of the controls need not be explicitly known. Numerical results for a variety of simple queueing models are presented.

Fleshing Out Wire Frames *by G. Markowsky and M. A. Wesley, p. 582.* Given a polyhedral object, its wire frame is the set of its edges and vertices. In this paper, we present an algorithm which discovers all objects with a given wire frame. This algorithm, which has a number of applications to mechanical design besides being of mathematical interest, has been implemented and has performed well on complex objects.

Digital System for Convergence of Three-Beam High-Resolution Color Data Displays *by J. S. Beeteson, K. T. Jarzebowski, and B. R. Sowter, p. 598.* This paper describes a new method of generating and adjusting convergence waveforms required by a delta-gun cathode-ray tube for digital color data display applications to ensure that the primary color images produced by three guns are correctly registered with respect to each other. The display is divided into 480 zones, and a number of correction values are associated with each zone. Digital values are converted into convergence currents using special smoothing techniques to ensure that quantizing effects do not cause unacceptable image distortion. A

microprogram is described which enables the total of 2016 digital correction values to be adjusted rapidly from the keyboard by a simple procedure using a crosshair adjustment pattern which is displayed sequentially at 13 positions on the screen. Special attention is paid to rounding errors which can occur during adjustment. Also accounted for in the waveform generation is the effect of phase delay between convergence coil current and its effect on the electron beams. Improvements necessary to the design of the radial and lateral convergence coil assemblies, normally found in the television industry, to reduce spot distortion and to improve sensitivity and temperature stability, are also presented. The design is realized in the IBM 3279 Color Display Station.

Macro Generation Algorithms for LSI Custom Chip Design *by B. Vergnieres, p. 612.* Presented in this paper are macro generation algorithms which have been developed and implemented for the optimization of physical and electrical designs of LSI macro circuits. Any type of logical macro circuit for a custom chip design can be automatically generated and optimized through the use of the concepts and numerical techniques for algorithmic layout generation and electrical network design which are described. The application of this design method to programmable logic array macros, which allow the generation of very attractive designs, is also discussed and illustrates the efficiency and flexibility of the macro generation concept.

Integral Point-Matching Method for Two-Dimensional Laplace Field Problems with Periodic Boundaries *by H. C. Lee and H. D. Chai, p. 622.* An integral point-matching technique is applied to two-dimensional Laplacian fields between periodic boundaries. This formulation leads to an algorithm that reduces the size of the matrix, economizing on computer workspace and inversion time. Several example problems solved on an APL terminal system are included.

Silicon Torsional Scanning Mirror *by K. E. Petersen, p. 631.* Conventional batch photolithography and thin film techniques are employed to fabricate an electrostatically driven torsional scanning mirror from single-crystal silicon. This device is extremely simple to make and operate, has operational characteristics comparable to commercial magnetically driven high-frequency scanners, and has exhibited a promising reliability.

A General Method for Channel Coding *by P. A. Franaszek, p. 638.* A procedure is described for constructing minimum delay codes for discrete noiseless channels. The method is based on a simple recursive algorithm for finding a set of coding paths.

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Preface *by S. S. Husson, p. 658.*

Improved Optimization of FORTRAN Object Programs *by R. G. Scarborough and H. G. Kolsky, p. 660.* For many years the FORTRAN H Extended compiler has produced highly optimized object programs for IBM System/360 and System/370 computers. A study of the object programs revealed, however, that important additional optimizations were possible, and the compiler has been enhanced accordingly. First, the range of cases handled by the optimization techniques already present in the compiler has been extended. For example, more duplicate computations are eliminated, and more invariant computations are moved from inner to outer loops. Second, several new optimizations have been added, with subscript computation and register allocation receiving particular attention. Third, certain optimization restrictions have been removed. This paper describes these improvements and reports their effects.

Optimization and Code Generation in a Compiler for Several Machines *by D. Boyle, P. Mundy, and T. M. Spence, p. 677.* This paper describes optimization techniques that have been implemented in a compiler which was designed to produce code comparable to that produced by hand. Additional optimization methods were incorporated into successive versions of the compiler. It was found that no single method was effective with all compiled programs but that each of the techniques described was effective for some programs.

Compilation to Compact Code *by B. Marks, p. 684.* A compilation process is described that emphasizes small object code rather than fast object code. The approach entails synthesizing an instruction set and an interpreter for that instruction set during compilation of an individual source program. Numerical results are given for compiling a systems programming subset of PL/I to System/370 code.

Strength Reduction for Division and Modulo with Application to Accessing a Multilevel Store *by J. Cocke and P. W. Markstein, p. 692.* A method for replacing certain division and modulo operations by additions and subtractions is presented. This optimization allows efficient and easy use of partitioned arrays to access a multilevel store.

The Experimental Compiling System *by F. E. Allen, J. L. Carter, J. Fabri, J. Ferrante, W. H. Harrison, P. G. Loewner, and L. H. Trevillyan, p. 695.* The Experimental Compiling System (ECS) described here represents a new compiler construction methodology that uses a compiler base which can be augmented to create a compiler for any one of a wide class of source languages. The resulting compiler permits the user to select code quality ranging from highly optimized to interpretive. The investigation is concentrating on easy expression and efficient implementation of language semantics; syntax analysis is ignored.

Some Techniques for Compile-Time Analysis of User-Computer Interactions *by J. M. Lafuente, p. 716.*

Compile-time techniques for analyzing user-computer interactions and the relationships and dependencies among items of data that exist during the execution of interactive application programs are presented. These techniques are useful in constructing efficient compilers for languages in which such interactions and data item relationships and dependencies are described by nonprocedural statements. The practical value of using nonprocedural descriptions is that they ease the task of the application programmer.

A Business Language *by N. J. Denil, p. 732.* The paper describes a language and supporting interactive system for use by the small businessman. To help the businessman-user understand and apply an application program expressed in the language, he can watch the application run in a single-step mode. If tailoring of the application program is necessary, the system guides the user by diagnosing inconsistencies in the modified program. The user controls production processing from the same user interface. In the first part of the paper, the language is described. Next some example user sessions are outlined. Finally the prototype implementation and some design issues are discussed.

A Language for Extended Queueing Network Models *by C. H. Sauer, E. A. MacNair, and S. Salza, p. 747.* Queuing networks are popular as models of performance of computer systems and communication networks. The Research Queueing Package, Version 2 (RESQ2), is a system for constructing and solving extended queuing network models. We refer to the class of RESQ2 networks as "extended" because of characteristics absent from most queuing models. RESQ2 incorporates a high-level language to concisely describe the structure of the model and to specify constraints on the solution. A main feature of the language is the capability to describe models in a hierarchical fashion, allowing an analyst to define parametric submodels which are analogous to macros or procedures in programming languages. RESQ2 thus encourages use of structured models to effectively evaluate complex systems.

Grammar Characterization of Flowgraphs *by J. L. Becerril, J. Bondia, R. Casajuana, and F. Valer, p. 756.* An extension of the scheme grammar concept given by Urschler is formalized. It is also shown that, in the usual hierarchy of the theory of formal languages, the language generated by the scheme grammar is regular (type 3). The last section gives the description of a system for the automatic structuring of programs, which applies these concepts to the Mills algorithm with some modifications.

A Data Definition Facility Based on A Value-Oriented Storage Model *by D. B. Lomet, p. 764.* A data definition facility is presented that provides a consistent description of both primitive and user data. It is based on a value-oriented storage model which carefully distinguishes between values and objects. It is values that are typed in this model, and operations of the type work explicitly on the values. Objects are accessible only via reference values. Objects are described via descriptors called templates, which ultimately yield reference type values. Operations, both primitive and user-defined, are part of a "machine interface," and all executable language constructs can ultimately be defined as explicit operations of the interface. Importantly, these operations must respect the typing constraints imposed by both the primitive types and the user extensions. The interactions of definition facility, storage model, and execution model are illustrated via a series of examples in which commonly user data constructs are defined.

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Network Problem-Determination Aids in Microprocessor-Based Modems *by S. Huon and R. Smith, p. 3.* Recent significant developments in large-scale integration (LSI) and in digital signal-processing techniques have combined to provide the base for a new generation of modems. LSI microprocessors now have the characteristics and performance to provide superior modem function as well as a design base for the addition of new function. The extendability afforded by a microprocessor-based modem design is being increasingly used to provide advanced communications network management functions. This paper describes the design objectives, implementation decisions, and design rationale for implementing these characteristics in the IBM 3863, 3864, and 3865 family of data modems. This network management function, which has been integrated into IBM Communications Network Management (CNM) offerings for IBM's Systems Network Architecture user networks, extends the problem-determination capability to cover the modems and communications lines. Support for this new function has been integrated into the 3705 ACF/NCP/VS control program and the System/370 NPDA program product.

A 2400-Bit/s Microprocessor-Based Modem *by D. Godard and D. Pilost, p. 17.* This paper describes the main characteristics of a new microprocessor-implemented 2400-bit/s data modem, the IBM 3863. In addition to the execution of signal processing tasks, the microprocessor provides a variety of other significant functions such as diagnostics and aids in network problem determination. The lack of hardware multiplication capability imposes certain constraints in the design of the signal processing algorithms. The analytical approach and computational techniques, based on the processing of signals in polar coordinates, which are used to circumvent these constraints, are described. It is shown in particular that timing phase control, carrier recovery, and adaptive equalization can be achieved at the receiver by processing only the phase of the sampled signal. Additionally, experimental results are presented which demonstrate the superiority of this design over conventional coherent demodulators.

Coupled Lossy Transmission Line Characterization and Simulation *by A. J. Gruodis and C. S. Chang, p. 25.* It has been shown that the frequency domain solution of the coupled lossy transmission line differential equations has a similar appearance to that of the single line. The frequency-dependent $n \times n$ characteristic admittance matrix Y_0 and propagation matrix Γ can be obtained from network analyzer insertion loss data treating the coupled transmission lines as a $2n$-port network. This paper develops a transient simulation technique for coupled lossy transmission lines based on frequency-dependent Y_0 and Γ data. Simulation results agree very well with transient measurements.

[Pt]Polypyrrole: A New Organic Electrode Material *by A. Diaz, J. M. Vasquez Vallejo, and A. Martinez Duran, p. 42.* Films of BF_4-doped polypyrrole grown on platinum, hereafter termed [Pt]polypyrrole, were used as electrodes in a series of reactions. These organic electrodes are found to be quite stable and nonporous; they generally do not perturb the redox reactions of dissolved species and they display rapid surface-substrate electron-transfer kinetics. The polypyrrole films are sensitive to the presence of Lewis bases in solution, which apparently act as nucleophiles, leading to degradation of the electrode properties.

Conducting Polymers: A Review of Recent Work *by G. B. Street and T. C. Clarke, p. 51.* The conductivities of all the currently reported conducting polymers are compared to those of the classical metals. The requirements for a technologically useful conducting polymer are considered and the degree to which existing conducting polymers meet these requirements is evaluated. The mechanism of doping is discussed together with the final state of the dopant and the polymer. The available structural data are described as well as the problems of structurally characterizing these systems. Some of the problems of inhomogeneous distribution of dopant species are also pointed out.

Computer Simulation of High-Resolution Electron Micrographs Using Dynamical Electron Scattering *by W. Krakow, p. 58.* A system of computer programs has been implemented that calculates both high-resolution images and diffraction patterns of generalized objects for the conventional transmission electron microscope. Multi-slice dynamical electron scattering of $256 \times 256 = 65{,}536$ beams is incorporated into these programs, which allows Bragg reflections and the diffuse scattering contributions between these reflections to be included in the computations. Images can therefore be obtained from imperfect crystalline structures and for disordered objects such as amorphous materials. Both bright- and dark-field images are obtained with this system in either the axial or tilted-beam imaging modes. Examples of surface effects in Au crystals, the [111] split Crowdion interstitial in tungsten, and an amorphous Fe film model are considered in the context of dynamical electron scattering.

Tomographic Reconstruction of Ultrasonic Attenuation with Correction for Refractive Errors *by K. M. Pan and C. N. Liu, p. 71.* The nonionizing and noninvasive characteristics of ultrasonics promote its increasing use in medical applications. Computerized ultrasonic attenuation tomography is one area where medically significant images may be reconstructed for diagnostic purposes. The objective of this work is to make an initial correction for refraction error and other problems present in computerized ultrasonic tomography. As a refinement of the scanning technique, our method attempts to provide high-quality projection profiles to the reconstruction algorithms. The important aspect of this new scanning mode lies in its correction for refraction in the measured attenuation profiles. In reconstructing phantom

targets scanned by our experimental system, results superior to traditional line-of-sight scanning were obtained.

A Number Representation Convertor for Magnetic Bubble String Comparators *by G. Bongiovanni and C.-K. Wong, p. 83.* Conventionally, there are four common ways to represent negative numbers, namely, 1's-complement, 2's-complement, signed-magnitude, and excess-2^{m-1}. In all these representations except the last one (excess-2^{m-1}), 1 is used as the sign bit to denote negative numbers. However, in a recently reported magnetic bubble device, using 1 as the sign bit for negative numbers may cause problems when two numbers are compared. In this paper we define a new number representation (called *B1's-complement*), and we propose a simple, read-free device for converting numbers represented in any of the above standard representations to either the excess-2^{m-1} or the B1's-complement representation.

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Preface *by S. S. Husson, p. 106.*

Techniques for Improving Engineering Productivity of VLSI Designs *by J. C. Logue, W. J. Kleinfelder, P. Lowy, J. R. Moulic, and W.-W. Wu, p. 107.* The ability of the semiconductor industry to produce chips with higher and higher circuit densities has created a challenge for the product designer: to utilize this capacity and still develop chips rapidly at reasonable cost. A multi-faceted approach to VLSI design is described that significantly reduces product development time and resource from those required with existing methods. This approach is based on the use of PLA structures or macros. It consists of a hardware/software modeling technique, use of laser-personalizable PLAs for rapid modeling of PLA macros, and a method for repairing design errors (that may hide other errors) on the actual VLSI wafers with a laser tool. A two-pass VLSI design is therefore highly probable.

Bipolar Circuit Design for a 5000-Circuit VLSI Gate Array *by A. H. Dansky, p. 116.* Ever-increasing gate-array chip circuit count and size pose challenges to the circuit designer, who must optimize the cell layout and power dissipation of logic circuits. This paper describes the design of a bipolar gate array for a 5000-circuit microprocessor. The physical design data obtained after completion of automatic placement and wiring are presented. The distribution of projected circuit delay for the 4437 nets is then calculated and this information is used to determine the selective increase in circuit power to reduce wide spreads in turn-off and turn-on delays. It is shown that this technique improves power/performance and has implications for future VLSI designs. It was also found that voltage drop violations were manageable even with the long net lengths occurring in this large VLSI gate array. Several commonly used bipolar circuit types are compared on the basis of capacitance drive capability at low power.

A 1024-Byte ECL Random Access Memory Using a Complementary Transistor Switch (CTS) Cell *by J. A. Dorler, J. M. Mosley, G. A. Ritter, R. O. Seeger, and J. R. Struk, p. 126.* This paper presents the design of a 1K-byte random access memory using a cross-coupled complementary transistor switch (CTS) cell. The memory operates with a 4.25-V power supply and achieves a 15-ns access time with a power dissipation of 1.8 W. This paper also demonstrates the advantages of using the CTS cell to achieve high circuit density and good performance of memory arrays. Array attributes, cell selection criteria, and cell operation (both ideal and in situ) as well as design considerations are covered. Hardware performance is also briefly summarized.

Delay Regulation—A Circuit Solution to the Power/Performance Tradeof *by E. Berndlmaier, J. A. Dorler, J. M. Mosley, and S. D. Weitzel, p. 135.* This paper introduces the concept of delay regulation as a means of controlling circuit delay variations from chip to chip, which is especially important in VLSI products. An embodiment of this concept which applies a phase-locked loop to individually control chip performance and power is presented together with computer-simulated results of an example design. It is shown that accurate delay equations and the potential for improved product yield result from application of the concept. The circuit overhead for large circuits is shown to be negligible. Application to a wide range of logic circuit types is also described.

A High-Density Bipolar Logic Masterslice for Small Systems *by J. Z. Chen, W. B. Chin, T.-S. Jen, and J. Hutt, p. 142.* A new high-density bipolar logic masterslice which uses a simple Schottky Transistor Logic (STL) circuit cell as its basic building block is presented in this paper. The STL cell is derived from Integrated Injection Logic (I^2L). The use of low-barrier Schottky diodes for AND logic, as diodes function in Diode Transistor Logic (DTL), makes possible achieving the NAND circuit operation. A brief description of the Schottky diode fabrication process is also given. A new concept of contact hole personalization is introduced and is shown to be an efficient approach to masterslice design as well as a factor in achieving high cell density. Due to the unusual structure of the basic cell and the arrangement of the cells in the masterslice, a new physical design methodology was developed for the design of different part numbers, corresponding to unique logic functions, on this masterslice. The STL circuit operates with a 1.7-V power supply and yields a typical delay of 3 ns at 0.5 mW and 5 ns at 0.15 mW. The I/O circuits are TTL-level compatible. The cells, the circuits, the unique features of the masterslice, and its application in an I/O controller chip are described.

Wire Length Distribution for Placements of Computer Logic *by W. E. Donath, p. 152.* It is shown from simple theoretical considerations that the distribution f_k of wire lengths for a good two-dimensional placement on a square

Manhattan grid should be of the form $f_k = g/k^{\gamma}$ $(1 \leq k \leq L)$ and $f_k \approx 0$ $(k > L)$, where γ is related to the Rent partitioning exponent p by the equation $2p + \gamma \approx 3$. Three placements were investigated and the distribution functions for wire length were found to follow the above relationships.

High-Speed Binary Adder *by H. Ling, p. 156.* Based on the bit pair (a_i, b_i) truth table, the carry propagate p_i and carry generate g_i have dominated the carry-look-ahead formation process for more than two decades. This paper presents a new scheme in which the new carry propagation is examined by including the neighboring pairs $(a_i, b_i; a_{i+1}, b_{i+1})$. This scheme not only reduces the component count in design, but also requires fewer logic levels in adder implementation. In addition, this new algorithm offers an astonishingly uniform loading in fan-in and fan-out nesting.

Statistics of Breakdown *by M. Shatzkes and M. Av-Ron, p. 167.* A derivation is given for the statistics of breakdown, including the effect of defects. The particular case where breakdowns are random in time and defects are randomly distributed is considered in detail. Results are obtained that are applicable to any kind of breakdown test. It is shown how relationships between the breakdown distributions for various breakdown tests and for different conditions in a particular test are generated. These relations are given for life tests (constant field) and for ramp tests (field proportional to time). It is found that an ordering of defect types according to their susceptibility to breakdown is not unique, but generally depends on the test conditions. This implies that the fields and temperatures used in screening procedures must be chosen with care.

Attraction Force Characteristics Engendered by Bounded, Radially Diverging Air Flow *by J. A. Paivanas and J. K. Hassan, p. 176.* When axially directed air flow enters a parallel plate passage through a hole in one of the plates, the ensuing diverging radial flow is such that a depressed pressure region occurs to some extent over the inlet region of the passage. If the plate against which the inlet air stream impinges is allowed to move freely, it will, under proper flow and other conditions, assume a position of stable equilibrium reflecting a balance among plate weight, the momentum repelling force of the stream, and a net restraining attraction force due to the radial pressure distribution in the passage. This phenomenon, the "Bernoulli" or "axi-radial" effect, has long been of interest in areas such as gas film lubrication and radial diffusers, and it has been applied extensively in IBM systems for contactless transport and motion control of semiconductor wafers on an air film. A steady, laminar, incompressible flow analysis for a representative axisymmetric circular disk model is presented here. A one-dimensional approach, using the general energy equation in conjunction with a passage flow friction factor variation, is applied to obtain an approximate relationship for radial pressure distribution. The friction factor, embodying the influence of varying viscous and inertial forces, is postulated on the basis of specialized radial flow studies in the literature. By also applying the momentum balance condition, an approximate overall solution is obtained which, for arbitrary model dimensions, describes the relationship among equilibrium passage spacing, resultant reaction fluid force and free disk weight, and a flow Reynolds number. The analytical predictions are compared with results from model experiments, and generally favorable agreement is indicated.

An On-Line Chinese Character Recognition System *by E. F. Yhap and E. C. Greanias, p. 187.* This paper describes an experimental system for the on-line recognition of handwritten Chinese characters. Constituent shapes of the characters are recognized as they are formed on an electronic tablet. The 72 constituent shapes can define a very large set of Chinese characters. The implementation described recognizes more than 2200 Chinese characters. More symbols can be added with relative ease. Experimental results are given for two writer populations.

A Magnetic Sensor Utilizing an Avalanching Semiconductor Device *by A. W. Vinal, p. 196.* A new semiconductor device for sensing uniaxial magnetic fields has been realized. The device is basically a dual-collector open-base lateral bipolar transistor operating in the avalanche region, and is referred to as a Magnetic Avalanche Transistor. It exhibits high magnetic transduction sensitivity compared to traditional Hall-effect and conventional nonlinear magnetoresistive devices. Several hundred experimental devices have been designed, fabricated, and tested over the past two years. Many structural and some process parameters were varied. The magnetic sensitivity of a typical device was found to be proportional to substrate resistivity. A sensitivity of 30 volts per tesla was measured for devices which used 5-ohm-cm *p*-type substrates. The output signal measured between collectors is differential and responds linearly with field magnitude and polarity. A typical signal-to-noise ratio is 20,000 per tesla. The bandwidth is known to extend well beyond 5 MHz. The sensitive area is calculated to be on the order of 5 μm^2. This communication describes the basic structure, fabrication, and characteristics for the magnetic avalanche transistor.

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Finite-Element Analysis of Semiconductor Devices: The FIELDAY Program *by E. M. Buturla, P. E. Cottrell, B. M. Grossman, and K. A. Salsburg, p. 218.* The FIELDAY program simulates semiconductor devices of arbitrary shape in one, two, or three dimensions operating under transient or steady-state conditions. A wide variety of physical effects, important in bipolar and field-effect transistors, can be modeled. The finite-element method transforms the continuum description of mobile carrier transport in a semiconductor device to a simulation model at a discrete number of points. Coupled and decoupled algorithms offer two methods of linearizing the differential equations. Direct

techniques are used to solve the resulting matrix equations. Pre- and post-processors enable users to rapidly generate new models and analyze results. Specific examples illustrate the flexibility and accuracy of FIELDAY.

Semiconductor Analysis Using Finite Elements—Part I: Computational Aspects *by G. D. Hachtel, M. H. Mack, R. R. O'Brien, and B. Speelpenning, p. 232.* We describe the computer implementation of SAFE, a general-purpose program for finite-element analysis of systems of nonlinear, nonvariational PDE. The form and nonlinearity of the PDE, as well as the domain, parameters, and boundary conditions of the problem, are user-specified. We discuss the problems of numerical integration in space and in time and describe the results of applying sparse-matrix methods to some practical problems. A method is given for unified treatment of nonstandard finite elements such as bicubic-spline and "current-continuous" elements. We give an assessment of the potential impact and reliability of general-purpose nonlinear finite-element programs. We conclude from out data that as the number of elements becomes large, sparse-matrix solutions dominate the overall operation count, even though the methods used are near-optimal for problems of moderate size.

Semiconductor Analysis Using Finite Elements—Part II: IGFET and BJT Case Studies *by G. D. Hachtel, M. H. Mack, and R. R. O'Brien, p. 246.* Semiconductor-like Applications of Finite Elements (SAFE), a novel, nonlinear, general-purpose two-dimensional finite-element code, is applied to problems in device modeling. Case studies of contemporary insulated gate field effect transistor (IGFET) and bipolar junction transistor (BJT) structures are given which demonstrate the reliability, versatility, and efficiency of finite-element methods in general and of the SAFE program in particular. The user-defined SAFE physical model is compared with experiments on a doubly implanted short-channel IGFET. Computer experiments are performed, indicating how to select the type, distribution, and numerical-integration method of finite elements for maximally efficient, assured-convergence, engineering-accuracy analysis, either steady state or transient.

Number of Vias: A Control Parameter for Global Wiring of High-Density Chips *by D. T. Lee, S. J. Hong, and C.-K. Wong, p. 261.* In integrated circuits, components are frequently interconnected by horizontal and vertical wires in respective wiring planes whether on chip, card, or board. The wire changes direction through "vias" that connect the orthogonal wiring planes. Because of technology constraints, the arrangement of vias must conform with certain neighborhood restrictions. We present results on the guaranteed minimum number and maximum possible number of vias in a given wiring cell for various technology constraints. These numbers provide an early means of control on global wiring routes to further the success of the exact embedding process that follows global wiring.

Logic Synthesis Through Local Transformations *by J. A. Darringer, W. H. Joyner, Jr., C. L. Berman, and L. Trevillyan, p. 272.* A logic designer today faces a growing number of design requirements and technology restrictions, brought about by increases in circuit density and processor complexity. At the same time, the cost of engineering changes has made the correctness of chip implementations more important, and minimization of circuit count less so. These factors underscore the need for increased automation of logic design. This paper describes an experimental system for synthesizing synchronous combinational logic. It allows a designer to start with a naive implementation produced automatically from a functional specification, evaluate it with respect to these many factors, and incrementally improve this implementation by applying local transformations until it is acceptable for manufacture. The use of simple local transformations in this system ensures correct implementations, isolates technology-specific data, and will allow the total process to be applied to larger, VLSI designs. The system has been used to synthesize masterslice chip implementations from functional specifications, and to remap implemented masterslice chips from one technology to another while preserving their functional behavior.

GRIN: Interactive Graphics for Modeling Solids *by W. Fitzgerald, F. Gracer, and R. Wolfe, p. 281.* This paper describes an experimental system for the original generation and subsequent modification of volume models of complex physical objects, using interactive computer graphics. The models are built up from primitive volumes, *e.g.*, cuboids, cylinders, swept surfaces, etc., entered by a mechanical engineer interacting with a two dimensional projection of the model on a graphic display screen. The primitives may be entered at any orientation in 3-space and combined to form a single polyhedral model. The central issue is the provision of an efficient, natural means for generating these models.

Propagation of 1-μm Bubbles in Contiguous Disk Devices *by K. Ju, H. L. Hu, R. G. Hirko, E. B. Moore, D. Y. Saiki, and R. O. Schwenker, p. 295.* Propagation margins of contiguous disk devices fabricated on both single- and double-layer garnet films have been measured. These performance measurements for 1-μm diameter magnetic bubble propagation were made on devices with cell sizes of 18 and 30 μm^2. The dependence of bias margin on ion-implantation conditions, material parameters, propagation pattern geometries, and temperature is discussed. Deuterium implantation is introduced, together with a new propagation pattern. Implantation with deuterium induces an anisotropy field change similar to that with hydrogen but with 50% smaller dosage. The new propagation pattern, with sawtooth-shaped tracks, reduces the interaction between charged walls of adjacent propagation tracks, thus resulting in improved performance at low bias fields.

Pi-Donor Intercalate Polymers: Synthesis, Charge-Transfer Interactions, and Applications *by F. B.*

Kaufman, p. 303. When low-ionization-potential organic donor molecules D such as tetrathiafulvalene, ferrocene, or triarylpyrazolines are chemically attached to a polymer backbone, a number of interesting and potentially useful phenomena are observed in films of the resulting polymers. For example, chemical oxidation, irradiation, or electrochemical treatment of these materials leads to a series of polymers, poly$[D_x(D^+A^-)_{1-x}]$, where D is the polymer-coupled organic molecule, x is the extent of oxidation, and A^- is the charge-compensating anion. Depending on the nature of the bound donor group, these polymers exhibit two kinds of electronic interactions between donor sites which are of charge-transfer origin. These phenomena are responsible for several important properties of this new class of materials that make them interesting as polymer-modified electrodes, as semiconducting polymers, and a high-resolution electron-beam (or x-ray) resists.

Computer Simulations of Complex Chemical Systems: Solvation of DNA and Solvent Effects in Conformational Transitions *by E. Clementi, p. 315.* As is known, atomic and small molecular systems can be realistically simulated with quantum-mechanical models. In complex chemical systems, however, the natural parameters for a description are not only the electronic density and energy but also entropy, temperature, and time. We have considered as an example for a complex chemical system the structure of water surrounding DNA with counterions. No direct experimental determination of the solvent structure around a single DNA macromolecule is available from experimental data, despite continuous efforts during the last twenty years to obtain both single crystals of DNA and scattering data from solutions. A very detailed representation is now available concerning the structure and interaction energy of water molecules in the first solvation shell or in the "grooves" of the DNA. The data obtained by our computer simulation are in good agreement with indirect data from DNA fibers at different relative humidities and with other indirect evidence. In addition, our simulated results allow us to present a preliminary model for the solvent effects in transition processes between different DNA conformations. The model presented is also in agreement with available experimental data. Finally, our results report the first determination of the position of counterions in DNA at different relative humidities and at room temperature. This application demonstrates the flexibility of the computational approach. The method we have used is very general; namely, it is not limited to a biological system but is valid for any organic or inorganic problem requiring systematic simulation on a class of compounds interacting either as a few molecules or as a large ensemble of molecules.

Positive First-Order Logic Is NP-Complete *by D. Kozen, p. 327.* The decision problem for positive first-order logic with equality is NP-complete. More generally, if Σ is a finite set of atomic sentences (i.e., atomic formulas of the form $t_1 = t_2$ or $Rt_1 \ldots t_n$ containing no variables) and negations of atomic sentences and if ϕ is a positive first-order sentence, then the problem of determining whether ϕ is true in all models of Σ is NP-complete.

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The Architecture of IBM's Early Computers *by C. J. Bashe, W. Buchholz, G. V. Hawkins, J. J. Ingram, and N. Rochester, p. 363.* Most of the early computers made by IBM for commercial production are briefly described with an emphasis on architecture and performance. The description covers a period of fifteen years, starting with the design of an experimental machine in 1949 and extending to, but not including, the announcement in 1964 of System/360.

System/360 and Beyond *by A. Padegs, p. 377.* The evolution of modern large-scale computer architecture within IBM is described, starting with the announcement of System/360 in 1964 and covering the latest extensions to System/370. Emphasis is placed on key attributes and on the motivation for providing them, and an assessment is made of the experience gained in the implementation and use of the architecture. The main approaches are discussed for obtaining implementations at widely differing performance levels, and a number of significant implementation parameters for all processors are listed.

IBM Data Communications: A Quarter Century of Evolution and Progress *by D. R. Jarema and E. H. Sussenguth, p. 391.* This paper describes the evolution of technological development in data communications at IBM. Rather than attempting to present a complete history, it emphasizes the changing environment and describes the more significant innovations that were incorporated in IBM's line of data communications products. Evolutionary developments in this area are traced from point-to-point batch transmission, to on-line batch communications, to interactive systems, and finally to networking. Although several aspects are treated, the primary focus of this account is on systems architecture, applications, and technology.

Real-Time Systems for Federal Applications: A Review of Significant Technological Developments *by P. F. Olsen and R. J. Orrange, p. 405.* The Federal Systems Division of IBM has been heavily involved in complex, on-line, real-time systems for over twenty-five years. In this paper a representative sample of these programs are reviewed, and an evaluation of the significant lessons learned from this wealth of experience is presented. The key issues which differentiate real-time systems from their more conventional data processing counterparts are identified and their implications are discussed. This leads to some conclusions regarding the kind of commitment that is necessary in order to succeed in the area of real-time applications.

Evolution of Real-Time Computer Systems for Manned Spaceflight *by S. E. James, p. 417.* This paper describes the evolution of ground-based command and control systems used

to support NASA's manned spaceflight program; it is an encapsulation of twenty years of development of real-time command and control systems at NASA's Real-Time Computer Complex (RTCC) in Houston, Texas. A brief description of manned spaceflight programs, their accomplishments, and IBM's involvement is provided as background information. Emphasis is given to the development of RTCC systems, as well as to the technological and architectural changes affecting this development. Also described are experiences gained in the management of complex, real-time software systems and the tools and techniques used in the development process.

Low-End General-Purpose Systems *by R. L. Taylor, p. 429.* Since the announcement of the IBM System/3 in 1969, IBM has been incorporating leading-edge technology in products referred to as small general-purpose systems. With the many models of the System/3, System/32, System/34, and System/38, IBM has introduced many technological advances addressing the needs of diverse customers, from the novice, first-time user to the experienced user in the distributed data processing account. By identifying the goals, objectives, design themes, major salient features, and development constraints, this paper reviews and highlights the technical evolution of these products in terms of their systems layout, processor architecture, machine structure, and programming support.

Evolution of Small Real-Time IBM Computer Systems *by T. J. Harrison, B. W. Landeck, and H. K. St. Clair, p. 441.* In parallel with the development of data processing applications for computers, effort was directed to other areas in which computers might provide benefits for the user. One early effort was the application of computers to the monitoring and control of industrial processes such as those used in oil refinery units, steel plants, and paper machines. Over time, these early efforts were generalized to a broader class of applications in which the computer was connected directly into an external *process* which placed time response requirements on the computer system. These systems have become known as *real-time systems*. In this paper, the evolution of IBM small real-time systems is traced from the late 1950s to the present. Emphasis is placed on a few features and requirements which characterize these systems.

Reliability, Availability, and Serviceability of IBM Computer Systems: A Quarter Century of Progress *by M. Y. Hsiao, W. C. Carter, J. W. Thomas, and W. R. Stringfellow, p. 453.* Computer systems have achieved significant progress in the areas of technology, performance, capability, and RAS (reliability/availability/serviceability) during the last quarter century. In this paper, we shall review the advances of IBM computer systems in the RAS area. This progress has for the most part been evolutionary; however, in some cases it has been revolutionary. RAS developments have been driven primarily by technological advances and by increases in functional capability and complexity, but RAS considerations have also played a leading role and have improved technological and functional capability. The paper briefly reviews the progress of computer technology. It points out how IBM has maintained or improved its systems RAS capabilities in the face of the greatly increased number of components and system complexity by improved system recovery and serviceability capability, as well as by basic improvements in intrinsic component failure rate. The paper also covers the CPU, tape, and disk areas and shows how RAS improvements in these areas have been significant. The main objective is to provide a comprehensive view of significant developments in the RAS characteristics of IBM computer systems over the past twenty-five years.

The Evolution of the MVS Operating System *by M. A. Auslander, D. C. Larkin, and A. L. Scherr, p. 471.* The mechanization of computer operations and the extension of hardware functions are seen as the basic purposes of an operating system. An operating system must fulfill those purposes while providing stability and continuity to its users. Starting with the data processing environment of twenty-five years ago, this paper describes the forces that led to the development of the OS/360 system design and then traces the evolution which led to today's MVS system.

The Origin of the VM/370 Time-Sharing System *by R. J. Creasy, p. 483.* VM/370 is an operating system which provides its multiple users with seemingly separate and independent IBM System/370 computing systems. These virtual machines are simulated using IBM System/370 hardware and have its same architecture. In addition, VM/370 provides a single-user interactive system for personal computing and a computer network system for information interchange among interconnected machines. VM/370 evolved from an experimental operating system designed and built over fifteen years ago. This paper reviews the historical environment, design influences, and goals which shaped the original system.

The IBM History of Memory Management Technology *by L. A. Belady, R. P. Parmelee, and C. A. Scalzi, p. 491.* The history of memory management technology in IBM during the period between the 1950s and the early 70s is discussed in this paper. The paper concentrates on the programming and operating system aspects of the problem, rather than the hardware technology involved.

Data Base Technology *by W. C. McGee, p. 505.* The evolution of data base technology over the past twenty-five years is surveyed, and major IBM contributions to this technology are identified and briefly described.

History of IBM's Technical Contributions to High Level Programming Languages *by J. E. Sammet, p. 520.* This paper discusses IBM's technical contributions to high level programming languages from the viewpoint of specific languages and their contributions to the technology. The

philosophy used in this paper is that it is the appropriate collection of features in a language which generally makes the contribution to the technology, rather than an individual feature. Those IBM languages deemed to have made major contributions are (in alphabetical order) APL, FORTRAN, GPSS, and PL/I. Smaller contributions (because of lesser general usage) have been made by Commercial Translator, CPS, FORMAC, QUIKTRAN, and SCRATCHPAD. Major contributions were made in the area of formal definition of languages, through the introduction of BNF (Backus-Naur Form) for defining language syntax and VDL (Vienna Definition Language) for semantics.

The History of Language Processor Technology in IBM *by F. E. Allen, p. 535.* The history of language processor technology in IBM is described in this paper. Most of the paper is devoted to compiler technology; interpreters, assemblers, and macro systems are discussed briefly. The emphasis is on scientific contributions and technological advances from a historical perspective. The synergistic relationship between theory and practice is a subtheme.

Formal Semantics of Programming Languages: VDL *by P. Lucas, p. 549.* The history of ideas that led to the first formalization of the syntax and semantics of PL/I is sketched. The definition method and notation are known as the Vienna Definition Language (VDL). The paper examines the relationship between VDL and both denotational semantics and the axiomatic approach to programming language definition.

IBM Contributions to Computer Performance Modeling *by Y. Bard and C. H. Sauer, p. 562.* Performance modeling can be used throughout the life of a computer system, from initial design, through implementation, configuration (and reconfiguration) and even tuning. Performance models are usually solved by numerical techniques, where possible, and by simulation, otherwise. This paper summarizes IBM's contributions to performance modeling and the solution of performance models.

Computer Modeling in Energy and the Environment *by H. P. Flatt, p. 571.* Computer modeling has played a significant role in the evaluation of possible sources of energy as well as the consequences of the use of energy on the environment. In this paper the contributions of IBM scientists to improve models in the fields of air pollution, solar energy, plasma physics, coal gasification, and energy conservation are summarized. These contributions include not only better numerical and programming techniques but improved mathematical models based upon advances in understanding of the physical processes involved.

Solid State Memory Development in IBM *by E. W. Pugh, D. L. Critchlow, R. A. Henle, and L. A. Russell, p. 585.* Memory technology in IBM processors has undergone a 280,000-fold increase in density, a 20,000 times decrease in power per bit, and a 10 to 100 times increase in speed during the last twenty-five years. These improvements have brought many advantages to users of information processing equipment, including a 650-fold reduction in the cost per bit of memory. During this period, processor memory technology evolved from cathode ray storage tubes in the early 1950s, through ferrite cores and thin magnetic films in the 1950s and 1960s, to bipolar and MOSFET semiconductor memories in the late 1960s through the 1970s. This paper describes these developments and the technical innovations that made them possible. It also describes continuing exploratory efforts, including work on magnetic bubbles—the newest solid state memory technology.

Semiconductor Logic Technology in IBM *by E. J. Rymaszewski, J. L. Walsh, and G. W. Leehan, p. 603.* In the last twenty-five years the performance of integrated circuits has improved by more than three orders of magnitude and the unit cost has been reduced by approximately the same factor. This paper describes the evolution of semiconductor logic technology in IBM from its early replacement of vacuum tubes in the mid-1950s to the beginnings of VLSI. It highlights the major challenges and accomplishments in the development of bipolar and field-effect transistor technologies and their embodiment in components for a wide spectrum of IBM products.

Electronic Packaging Evolution in IBM *by D. P. Seraphim and I. Feinberg, p. 617.* A quarter century of innovation in the development of packaging for semiconductors has culminated in the announcement of the IBM 4300 Series of computers and the IBM 3081. This technology has been built on a broad and expanding base starting with packaging for the 1400 Series in the late 1950s. In the next series, System/360, IBM chose to follow a unique approach which employed solder joints for the semiconductor connections, allowing ultimately a higher density and total number of interconnections compared to the rest of the industry. This has driven the packaging at the module level to achieve extremely high density and has led to multichip interconnections and multilayers on this first level of package. The dramatically increasing circuit function at the module level requires area arrays of pins to be able to get enough of them in a small area. Thus the next level (second level) of packaging has likewise been driven to provide many layers of dense interconnections to link to the module pins. New types of plated through holes join the many layers of interconnection. The highlights of the technical approaches which have been developed over the twenty-five-year period are discussed briefly in this paper.

Design Automation in IBM *by P. W. Case, M. Correia, W. Gianopulos, W. R. Heller, H. Ofek, T. C. Raymond, R. L. Simek, and C. B. Stieglitz, p. 631.* Within the context of the changing design requirements of digital systems spanning the semiconductor era, this paper describes the significant steps in the development of Design Automation technology in IBM. We cover the design tools which support the design of the

electronic portion of such systems. The paper emphasizes the systems approaches taken and the topics of design verification, test generation, and physical design. Descriptions of the technical contributions and interactions which have led to the unique characteristics of IBM's Design Automation systems are included.

Semiconductor Manufacturing in IBM, 1957 to the Present: A Perspective *by W. E. Harding, p. 647.* Over the past twenty-five years we have witnessed the transition from germanium-based, individual transistors in their hermetically sealed enclosures to VLSI silicon devices interconnected in modular packages containing more than 50,000 logic circuits or as many as 500,000 bits of random-access memory. During this progression, manufacturing facilities producing these modern products have become more complex and technologically more sophisticated than those of any other industry. This review traces these fast-moving changes as they have occurred in IBM, emphasizing the continuous expansion of manufacturing skills and disciplines and how these, in turn, have contributed to the development of today's products and their respective manufacturing systems.

The Evolution of Magnetic Storage *by L. D. Stevens, p. 663.* Since delivery of the first vacuum-column magnetic-tape transport in 1953 and the first movable-head disk drive in 1957, tape and disk devices in many configurations have been the principal means for storage of the large volumes of data required by data processing systems. Magnetic drums and other device geometries have also been important system components, but to a lesser extent. Over the past twenty-five years significant developments have been made that increase the capacity, reduce the cost, and improve the performance and reliability of these devices. With each improved device the range and nature of the applications undertaken have expanded and, in turn, led to a need for further device improvement. This paper gives a general review and historical perspective of magnetic storage development within IBM and is an introduction to the subsequent papers on disk, diskette, and tape technology and on disk manufacturing.

A Quarter Century of Disk File Innovation *by J. M. Harker, D. W. Brede, R. E. Pattison, G. R. Santana, and L. G. Taft, p. 677.* This paper traces the development of disk file technology from the first disk drive to the present. A number of innovative advances are reviewed in the evolution of mechanical design, materials, and processes. These advances constitute the technological base that has permitted almost four orders of magnitude of improvement in areal density; they are discussed from four interrelated aspects: the magnetic head and its air bearing support; the head positioning actuator; the disk substrate and its magnetic coating; and the read/write signal detection and clocking electronics.

Innovations in the Design of Magnetic Tape Subsystems *by J. P. Harris, W. B. Phillips, J. F. Wells, and W. D. Winger, p. 691.* This paper explores the selection of magnetic tape as an input/output medium for electronic computers and reviews the innovations in the development of magnetic tape and tape handling machines since their introduction in the early 1950s.

The IBM Diskette and Diskette Drive *by J. T. Engh, p. 701.* The diskette and diskette drive have had a major influence on data processing. They provide a low-cost, compact, high-performance solution to the need for a reusable magnetic medium and have largely replaced the punched card in many applications. Early applications were simple program-load functions. Today these have expanded to a wide range of medium exchange, information storage, and data processing applications. This paper examines the history of the development of these products within IBM. The discussion includes some of the alternatives considered and some of the problems encountered during these developments.

Innovations in Disk File Manufacturing *by R. B. Mulvany and L. H. Thompson, p. 711.* This paper discusses the important innovations in disk file manufacturing at IBM over the past twenty-five years. Technology advances in the key components of disk files—the magnetic read/write head, its air bearing support, and the disk substrate and magnetic coating—have permitted almost four orders of magnitude increase in areal recording density since the first disk file, the IBM 350, was shipped in 1957. Manufacturing capability for these basic recording technology components has been the key to realizing the cost/performance promise of each new technology. The evolution of this manufacturing capability is discussed with an emphasis on important innovations in processes, materials, tools, and testing techniques.

IBM Typewriter Innovation *by H. S. Beattie and R. A. Rahenkamp, p. 729.* The evolution of the writing machine from early eighteenth-century concepts to the modern electronic typewriter represents a rich history of innovative efforts by many individuals in several countries. This paper briefly highlights several significant early milestones and then draws particular attention to typewriter developments within the IBM Corporation. After entering the typewriter business in 1933, IBM expanded the applicability of electric typebar machines and introduced proportional spacing to electric typewriters. The IBM SELECTRIC® Typewriter single-print-element concept represented a major departure from traditional typewriter design. Since the introduction of the SELECTRIC Typewriter, it has evolved in several directions that resulted in the following: a typewriter to produce high-quality printing for cold-type composing applications; an input/output writer for use in terminals, computer consoles, and word processing machines; a typewriter that can correct errors by mechanically removing them from the page or covering them up; and electronic typewriters, using microcircuitry, that provide more memory and computing power than some early computers.

IBM Word Processing Developments *by F. T. May, p. 741.* IBM has been the leader in a variety of word processing

innovations since the introduction of the Magnetic Tape/SELECTRIC Typewriter in 1964 by the Office Products Division (OPD). Since then the basic approach of combining quality printed output and magnetic storage with new functions has been followed by OPD, while other IBM divisions have concentrated on new applications with data processing systems and shared-logic word processing systems. This article summarizes the major technical contributions by IBM that have supported the growth of an area of business that today is widely recognized as one of great potential for increased productivity in the modern office environment.

Printer Technology in IBM *by T. Y. Nickel and F. J. Kania, p. 755.* Major developments in printer technology have occurred during the past twenty-five years. Improvements in such areas as performance, reliability, and product cost are described in this paper, along with many of the IBM impact printer products embodying these developments, beginning with the well-known 1403 Line Printer.

Laser Electrophotographic Printing Technology *by C. D. Elzinga, T. M. Hallmark, R. H. Mattern, Jr., and J. M. Woodward, p. 767.* This paper describes the development of a non-impact printing technology—electrophotography with laser imaging—and explains its implementation, in both office product and system output devices. The key technical advances made during the development of the two devices are shown.

Semiconductors at IBM: Physics, Novel Devices, and Materials Science *by R. W. Keyes and M. I. Nathan, p. 779.* Work on semiconductor physics, devices, and materials science carried on at IBM in the last twenty-five years is reviewed. Topics covered include hot electrons, inversion layers, the injection laser, electroluminescence, the Gunn effect, MESFETs, solar cells, superlattices, and amorphous materials and effects.

Electronic Structure Theory *by P. S. Bagus and A. R. Williams, p. 793.* This paper reviews the history of IBM contributions over the last quarter century to electronic structure theory. The two main sections of the paper deal with large-scale computations in quantum chemistry and the study of the electronic structure of solids. The paper briefly discusses the methods of ab initio quantum chemistry, a field in which IBMers have devoted major effort and made substantial innovative, scientific contributions. Partly as a result of these contributions, it is now possible to use these methods to address theoretically problems of practical importance in chemistry. Major contributions toward understanding the electronic structure of solids, particularly with regard to metallic bonding, surface electronic structure, the nature of magnetism, and semiconductor defects, are discussed as well as pioneering efforts in the analysis of photoemission and low-energy electron diffraction data.

Phase Transitions *by K. A. Müller and E. Pytte, p. 811.* This paper presents a selective review of some of IBM's major contributions in the area of phase transitions during the last twenty-five years. It is separated into three main sections covering ferroelectric and structural transitions, magnetism, and nonequilibrium phase transitions.

Algebraic Complexity Theory *by N. Pippenger, p. 825.* Algebraic complexity theory, the study of the minimum number of operations sufficient to perform algebraic computations, is surveyed with emphasis on the general theory of bilinear forms and two of its applications: polynomial multiplication and matrix multiplication. Though by no means exhausting algebraic complexity theory, these topics illustrate well its development and its methods, and provide examples of its most striking successes.

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Design of Experiments in Computer Performance Evaluation *by M. Schatzoff, p. 848.* Techniques of statistical design of experiments have been successfully employed for many decades in a variety of applications in industry, agriculture, medicine, psychology, and other physical and social sciences. Their aim is to provide scientific and efficient means of studying the effects, on one or more variables of interest, of varying multiple controllable factors in an experiment. These techniques have not been widely used in the study of computer systems, although they can potentially have as large an impact as they have had in other fields. The purpose of this paper is to review some of the basic concepts underlying the statistical design and analysis of experiments and to illustrate them by means of examples drawn from studies of computer system performance. The examples include comparisons of alternate page replacement and free storage management algorithms, optimization of a scheduler, and validation of a system simulation model.

Adaptive Spectral Methods for Simulation Output Analysis *by P. Heidelberger and P. D. Welch, p. 860.* This paper addresses two central problems in simulation methodology: the generation of confidence intervals for the steady state means of the output sequences and the sequential use of these confidence intervals to control the run length. The variance of the sample mean of a covariance stationary process is given approximately by $p(0)/N$, where $p(f)$ is the spectral density at frequency f and N is the sample size. In an earlier paper we developed a method of confidence interval generation based on the estimation of $p(0)$ through the least squares fit of a quadratic to the logarithm of the periodogram. This method was applied in a run length control procedure to a sequence of batched means. As the run length increased the batch means were rebatched into larger batch sizes so as to limit storage requirements. In this rebatching the shape of the spectral density changes, gradually becoming flat as N increases. Quadratics were chosen as a compromise between small sample bias and large sample stability.

In this paper we consider smoothing techniques which adapt to the changing spectral shape in an attempt to improve both the small and large sample behavior of the method. The techniques considered are polynomial smoothing with the degree selected sequentially using standard regression statistics, polynomial smoothing with the degree selected by cross validation, and smoothing splines with the amount of smoothing determined by cross validation. These techniques were empirically evaluated both for fixed sample sizes and when incorporated into the sequential run length control procedure. For fixed sample sizes they did not improve the small sample behavior and only marginally improved the large sample behavior when compared with the quadratic method. Their performance in the sequential procedure was unsatisfactory. Hence, the straightforward quadratic technique recommended in the earlier paper is still recommended as an effective, practical technique for simulation confidence interval generation and run length control.

The Software-Cache Connection *by J. Voldman and L. W. Hoevel, p. 877.* This paper describes an adaptation of standard Fourier analysis techniques to the study of software-cache interactions. The cache is viewed as a "black box" Boolean signal generator, where "ones" correspond to cache misses and "zeros" correspond to cache hits. The spectrum of this time sequence is used to study the dynamic characteristics of complex systems and workloads with minimal *a priori* knowledge of their internal organization. Line spectra identify tight loops accessing regular data structures, while the overall spectral density reveals the general structure of instruction localities.

Approximate Solution of Queueing Networks with Simultaneous Resource Possession *by C. H. Sauer, p. 894.* Queueing networks are important as performance models of computer and communication systems because the performance of these systems is usually principally affected by contention for resources. Exact numerical solution of a queueing network is usually only feasible if the network has a product form solution in the sense of Jackson. An important network characteristic which apparently precludes a product form solution is simultaneous resource possession, *e.g.*, a job holds memory and processor simultaneously. This paper extends previous methods for approximate numerical solution of queueing networks with homogeneous jobs and simultaneous resource possession to networks with heterogeneous jobs and simultaneous resource possession.

Collision-Free Local Area Bus Network Performance Analysis *by V. C. Hamacher and G. S. Shedler, p. 904.* This paper deals with port access control for local area computer communication bus networks. Emphasizing properties of the algorithms and delay-throughput performance, we focus on two collision-free access control schemes recently proposed by Eswaran, Hamacher, and Shedler. We also provide a comparison of these schemes to other available bus access techniques. The performance analysis is based on representation of the bus network as a closed queueing system with nonpreemptive priority service.

Delay Analysis of a Two-Queue, Nonuniform Message Channel *by S. B. Calo, p. 915.* A Message Channel is defined as a tandem connection of single server queues in which the successive service times experienced by any particular customer are scaled versions of the same random variable, and thus it serves as a model for sparsely connected store-and-forward data communications networks (or network segments) where messages typically preserve their lengths as they traverse the system. A particular instance of such a nonstandard queueing model is analyzed in this paper. The system consists of two single server queues in tandem subject to a Poisson arrival process (at the first queue) and providing service according to scaled versions of a sequence of two-level, discrete random variables. A set of recursive equations that can be used to solve the model for any given scaling factor at the second queue (normalized with respect to the first queue service) is explicitly derived. In addition, complete solutions are displayed for several cases of interest, and the equilibrium mean cumulative waiting times for these instances are compared as a method of indicating the impact of the scaling factor on the operation of the system. The extension of several results to systems with more general service time processes is discussed.

Message Reassembly Times in a Packet Network *by G. Stroebel, p. 930.* This paper addresses the problem of computing the reassembly time of a multipacket message. All packets from a single message are assumed to flow in sequence along the same physical path. The analysis includes the effects of contention between messages in the network on the delay time at each station along the path and its impact on message reassembly time.

Fleshing Out Projections *by M. A. Wesley and G. Markowsky, p. 934.* In an earlier paper, the authors presented an algorithm for finding all polyhedral solid objects with a given set of vertices and straight line edges (its *wire frame*). This paper extends the Wire Frame algorithm to find all solid polyhedral objects with a given set of two dimensional projections. These projections may contain depth information in the form of dashed and solid lines, may represent cross sections, and may be overall or detail views. The choice of labeling conventions in the projections determines the difficulty of the problem. It is shown that with certain conventions and projections the problem of fleshing out projections essentially reduces to the problem of fleshing out wire frames. Even if no labeling is used, the Projections algorithm presented here finds all solutions even though it is possible to construct simple examples with a very large number of solutions. Such examples have a large amount of symmetry and various accidental coincidences which typically do not occur in objects of practical interest. Because of its generality, the algorithm can handle pathological cases if they

arise. This Projections algorithm, which has applications in the conversion of engineering drawings in a Computer Aided Design, Computer Aided Manufacturing (CADCAM) system, has been implemented. The algorithm has successfully found solutions to problems that are rather complex in terms of either the number of possible solutions or the inherent complexity of projections of objects of engineering interest.

An Emulation System for Programmable Sensory Robots *by J. Meyer, p. 955.* This paper describes EMULA, an experimental interactive system for the emulation of sensory robots. EMULA was constructed as a bridge between an existing language for driving actual robots and an existing geometric modeling system. The modeling system was extended to handle mechanisms, such as robots, and an emulation language was introduced to indicate certain specific physical effects, including sensory feedback, grasping and releasing of parts, and gravity. EMULA allows manipulation programs to be tested by users in interactive terminal sessions or in batch mode. Monitoring functions are provided to record actions, store selected views, and check for collisions.

Impact of a Liquid Drop Against a Flat Surface *by S. E. Bechtel, D. B. Bogy, and F. E. Talke, p. 963.* Lagrangian methods are used with an assumed flow field and a truncated sphere model to analyze the dynamical process of a liquid drop impacting a flat, rigid surface. The resulting differential equation for drop height as a function of time during contact is solved numerically for several values of the three parameters: Weber number of the incoming drop, ratio of the surface tension in air to that at the contact surface, and the viscosity parameter. The drop contact radius as a function of time is also calculated and compared with some experimental results in the literature.

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System Development and Technology Aspects of the IBM 3081 Processor Complex *by M. S. Pittler, D. M. Powers, and D. L. Schnabel, p. 2.* The IBM 3081 Processor Complex consists of a 3081 Processor Unit and supporting units for processor control, power, and cooling. The Processor Unit, completely implemented in LSI technology, has a dyadic organization of two central processors, each with a 26-ns machine cycle time, and executes System/370 instructions at approximately twice the rate of the IBM 3033. This paper presents an overview of the advances in technology and in the design process, as well as enhancements in the system design that were associated with the development of the IBM 3081. Application of LSI technology to the design of the 3081 Processor Unit, which contains almost 800,000 logic circuits, required extensions to silicon device packaging, interconnection, and cooling technologies. A key achievement in the 3081 is the incorporation of the thermal conduction module (TCM), which contains as many as 45,000 logic circuits, provides a cooling capacity of up to 300 W, and allows the elimination of one complete level of packaging—the card level. Reliability and serviceability objectives required new approaches to error detection and fault isolation. Innovations in system packaging and organization, and extensive design verification by software and hardware models, led to the realization of the increased performance characteristics of the system.

IBM 3081 Processor Unit: Design Considerations and Design Process *by R. N. Gustafson and F. J. Sparacio, p. 12.* Significantly new challenges were presented for the design of the 3081 Processor Unit since it was the first IBM large system implemented in LSI technology. Solutions had to be found for a new set of problems in order to achieve the required product objectives while maintaining an acceptable development cost and schedule. In this paper, the design aspects and the characteristics of the 3081 Processor Unit are described and the tradeoffs that were made due to the implementation of LSI are presented. A design strategy was chosen that included tradeoffs covering the areas of machine organization, performance level, implementation costs, testing and servicing aids, and development schedules. An innovative verification effort was introduced into the design process, capitalizing on a hardware flowcharting discipline and rigorous design rules. On the basis of this development experience, some thoughts concerning VLSI implementations are explored.

Processor Controller for the IBM 3081 *by J. Reilly, A. Sutton, R. Nasser, and R. Griscom, p. 22.* The IBM 3081 represents an important step in the evolution of large-scale data processing systems. The incorporation of LSI technology in its design has resulted in a departure from the use of traditional support tools and techniques. Its increased processing capabilities and its dyadic organization have further accented the requirements for high availability and ease of operation. This paper describes the Processor Controller unit of the 3081 Processor Complex, which handles the functions of maintenance, monitoring, and control of the system. It discusses how this unit has dealt with these changes to keep pace with the demands of advanced technology and improved system availability. In providing the necessary test and support functions of reset and manual control, the Processor Controller exploits the level-sensitive scan design capability of the 3081 to obtain read/write access to all latches and arrays. This design approach, coupled with significantly expanded capabilities for error recovery, configuration control, and diagnostics, has significantly affected the structure and capabilities of the Processor Controller.

Thermal Conduction Module: A High-Performance Multilayer Ceramic Package *by A. J. Blodgett and D. R. Barbour, p. 30.* Innovations in package design coupled with major advances in multilayer ceramic (MLC) technology provide a high-performance LSI package for the IBM 3081 Processor Unit. The thermal conduction module (TCM) utilizes a 90 × 90-mm MLC substrate to interconnect up to 118 LSI devices. The substrate, which typically contains 130 m of impedance-controlled wiring, provides an array of 121 pads for solder connections to each device and an array of 1800 pins for interconnection with the next-level package. A unique thermal design provides a cooling capacity of up to 300 W. This paper describes the TCM design and outlines the processes for fabrication of these modules. The TCM is compared to prior technologies to illustrate the improvements in packaging density, reliability, and performance.

A New Set of Printed-Circuit Technologies for the IBM 3081 Processor Unit *by D. P. Seraphim, p. 37.* A new set of printed-circuit technologies have been developed which permit construction of printed-circuit panels with several kilometers of controlled-impedance interconnections. Communications between internal layers of signal planes are achieved through small plated vias (drilled with a laser), while plated through-holes are used for the logic service terminals for cable terminations and module terminals. The panels are the largest currently known in the industry, 600 × 700 mm, and have the most layers, 20. This paper describes new LSI package designs which are achievable with the exceptional versatility that the new technologies provide. These technologies encompass vacuum lamination, electroless plating, photosensitive dielectric, laser drilling, automatic twisted-pair wire bonding, and other new approaches to printed circuits.

Conduction Cooling for an LSI Package: A One-Dimensional Approach *by R. C. Chu, U. P. Hwang, and R. E. Simons, p. 45.* The introduction of LSI packaging has significantly increased the number of circuits per silicon chip, and at the same time has greatly increased their heat flux density. In comparison to earlier MST (monolithic systems technology) products, the heat flux which must be removed from the new multi-chip substrates (100 or more chips) has

increased by an order of magnitude or more. This paper discusses an innovative conduction-cooling approach using He gas encapsulation which has been developed in response to the new LSI technology requirements. Background is provided on the liquid-encapsulated-module technology which preceded the new approach, and the basic challenges encountered in building a thermal bridge from individual chips to the module and cold plate are described. The underlying theory of operation is presented using one-dimensional mathematical and discrete analog models. The effects of various factors such as geometry, chip tilt, He concentration, air leakage, and materials are illustrated using these models. A thermal sensitivity analysis is performed to determine variations in junction temperatures and the contributions of the major parameters. The companion paper by Oktay and Kammerer which follows this one treats the more general "multi-dimensional" approach using numerical analysis techniques.

A Conduction-Cooled Module for High-Performance LSI Devices *by S. Oktay and H. C. Kammerer, p. 55.* The advent of LSI chip technology makes possible significantly increased performance and circuit densities by means of large-scale packaging of multiple devices on a single multi-layer ceramic (MLC) substrate. Integration at the chip and module levels has resulted in circuit densities as high as 2.5×10^7 circuits per cubic meter, with the necessity of removing heat fluxes on the order of 100 kW/m^2. This paper describes the development and implementation of a novel packaging concept which meets the stringent and highly interactive demands on cooling, reliability, and reworkability of LSI technology. These requirements resulted in an innovative packaging approach, referred to as the thermal conduction module (TCM). The TCM uses individually spring-loaded "pistons" that contact each chip with helium gas, the conducting medium for removing heat efficiently. A dismountable hermetic seal makes multiple access possible for device and substrate rework, while ensuring mechanical and environmental protection of critical components. A wide range of thermal, mechanical, and environmental experiments are described with analytical and computer models. The one-dimensional approach used in the previous paper by Chu et al. is extended to three-dimensional computer modeling. Simulations of expected chip temperature distributions in the IBM 3081 Processor Unit are discussed. Enhanced thermal performance of the advanced packaging concept for future applications is also indicated.

Model for Transient and Permanent Error-Detection and Fault-Isolation Coverage *by D. C. Bossen and M. Y. Hsiao, p. 67.* As computer technologies advance to achieve higher performance and density, intermittent failures become more dominant than solid failures, with the result that the effectiveness of any diagnostic procedure which relies on reproducing failures is greatly reduced. This problem is solved at the system level by a new strategy of dynamic error detection and fault isolation based on error checking and analysis of captured information. The model developed in this paper allows the system designer to project the dynamic error-detection and fault-isolation coverages of the system as a function of the failure rates of components and the types and placement of error checkers, which has resulted in significant improvements to both detection and isolation in the IBM 3081 Processor Unit. The model has also resulted in new probabilistic isolation strategies based on the likelihood of failures. Our experiences with this model on several IBM products, including the 3081, show good correlation between the model and practical experiments.

Automated Diagnostic Methodology for the IBM 3081 Processor Complex *by N. N. Tendolkar and R. L. Swann, p. 78.* The concepts of automated diagnostics that were developed for and that are implemented in the IBM 3081 Processor Complex are presented in this paper. Significant features of the 3081 diagnostics methodology are the capability to isolate intermittent as well as solid hardware failures, and the automatic isolation of a failure to the failing field-replaceable unit (FRU) in a high percentage of the cases. These features, which permit a considerable reduction in the time to repair a failure as compared to previous systems, are achieved by designing a machine which has a very high level of error-detection capability as well as special functions to facilitate fault isolation using Level-Sensitive Scan Design (LSSD), and which includes a Processor Controller to implement diagnostic microprograms. Intermittent failures are isolated by analyzing data captured at the detection of the error, and the analysis is concurrent with customer operations if the error is recoverable. A further improvement in the degree of isolation is achieved for solid failures by using automatically generated validation tests which detect and isolate stuck faults in the logic. The diagnostic package was designed to meet a specified value of isolation effectiveness, stated as the average number of FRUs replaced per failure. The technique used to estimate the isolation effectiveness of the diagnostic package and to evaluate proposals for improving isolation is described. Testing of the diagnostic package by hardware bugging indicates very good correlation between projected and measured effectiveness.

Design Verification System for Large-Scale LSI Designs *by M. Monachino, p. 89.* This paper describes the changing environment of large-scale hardware designs as influenced by technology advancements and the growing use of design verification in the design implementation process. The design verification methodology presented here saved some 66% from the 3081 product schedule, when compared with a schedule utilizing a conventional verification method, on almost 800,000 LSI logic circuits. The paper discusses the use of software modeling techniques to verify LSI hardware designs, methods used for deciding when modeling should be stopped and hardware can be built with sufficient assurance to permit additional verification to continue on the hardware, methods for testing the hardware as it is assembled into a very large processor complex, and the organization of the design

verification system to avoid duplicate creation of test cases for different stages of the design process. Experiences encountered in designing and verifying the 3081 system, a discussion of some shortcomings, and an endorsement of certain techniques and improvements for use in future designs are also presented.

Timing Analysis of Computer Hardware *by R. B. Hitchcock, Sr., G. L. Smith, and D. D. Cheng, p. 100.* Timing Analysis is a design automation program that assists computer design engineers in locating problem timing in a clocked, sequential machine. The program is effective for large machines because, in part, the running time is proportional to the number of circuits. This is in contrast to alternative techniques such as delay simulation, which requires large numbers of test patterns, and path tracing, which requires tracing of all paths. The output of Timing Analysis includes "slack" at each block to provide a measure of the severity of any timing problem. The program also generates standard deviations for the times so that a statistical timing design can be produced rather than a worst case approach. This system has successfully detected all but a few timing problems for the IBM 3081 Processor Unit (consisting of almost 800,000 circuits) prior to the hardware debugging of timing. The 3081 is characterized by a tight statistical timing design.

Boolean Comparison of Hardware and Flowcharts *by G. L. Smith, R. J. Bahnsen, and H. Halliwell, p. 106.* Boolean comparison is a design verification technique in which two logic networks are compared for functional equivalence using analysis rather than simulation. Boolean comparison was used on the IBM 3081 project to establish that hardware flowcharts and the detailed hardware logic design were functionally equivalent. Hardware flowcharts are a graphic form of a hardware description language which describes the logical behavior of the machine in terms of the inputs, outputs, and latches. The logical correctness of the hardware flowcharts was previously established via cycle simulation. The concepts and techniques of Boolean comparison as used on the IBM 3081 project are described.

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Laser-Enhanced Plating and Etching: Mechanisms and Applications *by R. J. von Gutfeld, R. E. Acosta, and L. T. Romankiw, p. 136.* We have developed experimental electroplating, electrodeless plating, and etching techniques that use a focused laser beam to define the localized plating or etching region. Enhancements in plating (etching) rates up to $\approx 10^3$ to 10^4, compared to background rates, have been observed in the region of laser irradiation. A thermal model has been developed to describe the observed effects over the entire overpotential (polarization) curve. In the low overpotential region the enhancement is dominated by the increase in the local charge-transfer kinetics due to the local increase in temperature produced by absorption of the laser energy by the cathode (anode). At higher overpotentials, in the mass-transport-limited region, the main enhancement occurs due to hydrodynamic stirring caused by the large local temperature gradients. Examples of gold, nickel, and copper electroplating are described to illustrate the value of this technique for micron-sized circuit personalization and repair. Additional examples of electroless laser-enhanced plating and exchange plating are also described.

Laser-Enhanced Chemical Etching of Solid Surfaces *by T. J. Chuang, p. 145.* The laser-enhanced chemical etching of Si, SiO_2, Ta, and Te films with halogen-containing gases excited by a pulsed CO_2 laser and a continuous-wave (cw) Ar^+ laser has been studied. Detailed measurements of the etch rates as functions of the laser frequency, the laser intensity, and the gas pressure have been performed for some of the gas-solid systems. The enhanced surface reactions have been classified into three categories: those activated by the vibrational excitation of the etchant molecules, those with radicals generated by photodissociation, and those induced by laser excitation of solid substrates. Examples which illustrate the effects of laser radiation on these surface photochemical processes are given. Achievable etch rates and spatial resolutions for the various reaction mechanisms are also examined.

Ultrafast High-Resolution Contact Lithography with Excimer Lasers *by K. Jain, C. G. Willson, and B. J. Lin, p. 151.* A new technique for speckle-free, fine-line high-speed lithography using high-power pulsed excimer lasers is described and demonstrated. Use of stimulated Raman shifting is proposed for obtaining the most desirable set of spectral lines for any resist. This permits, for the first time, the optimization of the exposure wavelengths for a given resist, rather than the reverse situation. Excellent-quality images are obtained in 1-μm-thick diazo-type photoresists such as ®AZ-2400 and a diazonaphthoquinone-®Novolak resist system by means of contact printing with a XeCl laser at 308 nm and a KrF laser at 248 nm. Resolution down to 1000 line pairs per millimeter is experimentally demonstrated. These images are comparable to state-of-the-art contact lithography obtained with conventional lamps. The major difference is that the excimer laser technique is approximately two orders of magnitude faster. Tests on reciprocity failure in several resists indicate a decrease in sensitivity by only a factor of three, despite the $\approx 10^8$ times larger power density used in the laser exposures. The possibility of photochemical reactions being different from those taking place in the case of lamp exposures is discussed in view of these results.

Image Projection with Nonlinear Optics *by M. D. Levenson and K. Chiang, p. 160.* The nonlinear optical process of conjugate wavefront generation by degenerate four-wave mixing can project images in a manner akin to conventional optical systems. The underlying physics is quite different, and the difference allows higher resolution over larger useful fields. This article reviews the basics of conjugate wavefront generation and its relationship to holography, and proposes

applications in fine-line lithography. Initial experiments confirm the predicted advantages but also point out inadequacies in present-day nonlinear optics technology.

Modification of Semiconductor Device Characteristics by Lasers *by Y. C. Kiang, J. R. Moulic, W.-K. Chu, and A. C. Yen, p. 171.* The paper discusses an emerging area of laser-semiconductor processing: the effect of laser irradiation on the electrical parameters of diffused-junction devices. Shallow diffusions of 0.2- to 0.5-μm depths have been achieved. Transistor current gains have been modified and the results agree with the theoretical analysis.

The Application of GaAlAs Lasers to High-Resolution Liquid-Crystal Projection Displays *by A. G. Dewey and J. D. Crow, p. 177.* In this review we describe a high-resolution liquid-crystal (LC) display that uses multiple GaAlAs lasers to write on the LC cell. Arrays of high-powered lasers were needed to meet the writing speed requirements of the display. A fiber optic delivery system was developed to allow high-resolution, multi-spot writing on the cell, regardless of the laser configuration used. The flexibility and unconstrained length of the fiber optics also permitted simplification in the design of the scanner system which moved the optical beams over the LC cell. Because of the proximity of the injection laser's wavelength to the visible spectrum used in the display projection system, and because of divergence of the beams in the optical delivery system, a reflective LC cell was designed. Almost total absorption of the GaAlAs laser beam was achieved. This paper discusses the thermal and optical properties of the cell and their effect on the writing characteristics and the quality of the projected image (contrast and brightness). An off-axis projection system, which was designed for use with the reflective cell, creates a high-resolution image on the screen.

Lasers in Electrophotography *by A. C. Tam and R. D. Balanson, p. 186.* We review the recent advances in the use of laser sources in the field of electrophotography. New experimental investigations of the photogeneration and transport processes utilized in electrophotography are now possible because of the short pulse duration, high peak power, high collimation, monochromaticity, and/or coherence of a laser source. Also, the increasing availability of reliable and inexpensive lasers has resulted in many new technological uses of lasers in electrophotographic applications. In addition to the continued use of HeNe and HeCd lasers, new products have been configured with GaAs lasers.

Multiple Photochemical Hole Burning in Organic Glasses and Polymers: Spectroscopy and Storage Aspects *by A. R. Gutiérrez, J. Friedrich, D. Haarer, and H. Wolfrum, p. 198.* A scheme for optical information storage using photochemical hole burning (PHB) in amorphous systems is evaluated. Limits imposed by the nature of PHB in polymers and glasses and its dependence on temperature are discussed. It is demonstrated that optical information storage can be multiplexed by a factor of 10^3 using the frequency dimension and PHB.

Integrated Optics and Raman Scattering: Molecular Orientation in Thin Polymer Films and Langmuir-Blodgett Monolayers *by J. F. Rabolt, R. Santo, N. E. Schlotter, and J. D. Swalen, p. 209.* Studies of submicron films and molecular monolayers with infrared and Raman spectroscopy have been hampered by the inability of current spectroscopic techniques to detect the minute amount of material present in these thin-film assemblies. A method for overcoming this problem by using integrated optics has been successfully demonstrated. In the case of Raman studies, the material whose spectrum was desired was made into an asymmetric slab waveguide or a composite waveguide structure in which both the optical field intensity of the in-coupled laser source and the scattering volume of the sample have been significantly increased. Using this technique we have obtained Raman spectra of thin polymer films (<80 nm) and the resonant Raman spectra of single dye monolayers (2.7 nm). Estimates of molecular orientation within the two-dimensional films have been made based on the results of polarized Raman measurements. In addition, the results of overcoating experiments illustrate the versatility and applicability of this technique to a wide variety of surface and thin-film studies.

A New Class of Materials for Holography in the Infrared *by C. Bräuchle, U. P. Wild, D. M. Burland, G. C. Bjorklund, and D. C. Alvarez, p. 217.* A new class of holographic materials is described. These materials undergo four-level two-photon photochemistry. The holograms recorded in these materials are self-developing and are not erased during reading. Furthermore, the recording process may be gated off and on by using an auxiliary incoherent light source. As a specific example of such a system, holograms formed using samples of an α-diketone dissolved in poly(cyanoacrylate) are described. Gated holograms have been recorded in this material at 752 and 1064 nm.

Holography in the IBM 3687 Supermarket Scanner *by L. D. Dickson, G. T. Sincerbox, and A. D. Wolfheimer, p. 228.* The IBM 3687 Supermarket Scanner is described, with emphasis on the holographic deflector disk used to create the scan pattern. The scanner exploits the functional advantages of holography to create a dense, multiple-focal-plane scan pattern with small spot size and large depth of field. The optical design of the holographic disk is discussed and basic disk fabrication concepts are introduced.

Laser-Induced Arcing in Cathode Ray Tubes *by R. T. Hodgson, A. B. Minn, and J. D. Rockrohr, p. 235.* Laser-induced arcing in cathode ray tubes has been used to study the effect of spontaneous internal high-voltage arcs under normal operating conditions. Ruby and Nd:YAG laser systems were compared as laser sources for the breakdown.

Various arc-suppression schemes for CRT systems were evaluated for future use.

Performance Analysis of Suspend Locks in Operating Systems *by J. Hofmann and H. Schmutz, p. 242.* Performance models of suspend locks in operating systems are developed and analyzed. Analytical expressions and algorithms for numerical results have been obtained for an arbitrary number of processors, an arbitrary number of tasks, and one suspend lock. The results are discussed and important dependencies among the major characteristic quantities such as queue length, processor speed, number of processors, dispatching overhead, and processor degradation are shown. Expressions are derived permitting the control program designer to estimate the system impact of locking during the early design phase.

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Cost/Performance Single-Chip Module *by D. J. Bendz, R. W. Gedney, and J. Rasile, p. 278.* The introduction of the high performance T^2L device technology for the IBM 4300 Systems and the System/38 required extensions of the 24-mm metallized ceramic module used in prior IBM systems. The extension of the metallized ceramic technology into a physically larger 28-mm module, electrically enhanced with a reference plane and with fine line (0.025-mm) wiring, is described. The reliability of this module was evaluated with particular emphasis on corrosion and metal migration in humid environments and on exposure to atmospheric contaminants.

The Thin-Film Module as a High-Performance Semiconductor Package *by C. W. Ho, D. A. Chance, C. H. Bajorek, and R. E. Acosta, p. 286.* This paper discusses a multichip module for future VLSI computer packages on which an array of silicon chips is directly attached and interconnected by high-density thin-film lossy transmission lines. Since the high-performance VLSI chips contain a large number of off-chip driver circuits which are allowed to switch simultaneously in operation, low-inductance on-module capacitors are found to be essential for stabilizing the on-module power supply. Novel on-module capacitor structures are therefore proposed, discussed, and evaluated. Material systems and processing techniques for both the thin-film interconnection lines and the capacitor structures are also briefly discussed in the paper. Development of novel defect detection and repair techniques has been identified as essential for fabricating the Thin-Film Module with practical yields.

Advanced Printed-Circuit Board Design for High-Performance Computer Applications *by R. F. Bonner, J. A. Asselta, and F. W. Haining, p. 297.* A new integrated circuit packaging structure was needed to support the new 90-mm multilayer ceramic modules, known as Thermal Conduction Modules (TCMs), used in the IBM 3081 computers. The structure developed eliminates one level of packaging (the card level) and allows up to nine TCMs to be plugged directly into a large multilayer printed-circuit board using a new zero-insertion-force connector system. The board has 18 internal circuit planes for signal and power distribution and accommodates new signal cabling, power bus, terminating resistors, decoupling capacitors, and cooling hardware, forming a packaged unit of up to a quarter million logic gates and half a million bits of memory. This paper focuses on the detailed design of the printed-circuit board and on its signal and power transmission characteristics.

High-Density Board Fabrication Techniques *by J. R. Bupp, L. N. Chellis, R. E. Ruane, and J. P. Wiley, p. 306.* A variety of construction methods can be used to form high-density printed-circuit boards. The electrical and mechanical requirements of a design strongly influence the choice of processes used to produce the finished product. The introduction of physically large high-density boards required the development of many new processes, several of which are critical to the electrical performance of the composite. In this paper the process sequence employed in the fabrication of the 3081 high-density board is described, with particular emphasis on the selection of the critical processes used in its manufacture. The 3081 registration system is also discussed, and a new method for merging through-hole location data with the data representing the location of the conducting layers is presented.

Development of Interconnection Technology for Large-Scale Integrated Circuits *by R. Babuka, G. J. Saxenmeyer, Jr., and L. K. Schultz, p. 318.* The size, cost, reliability, and serviceability of modern large data processing systems are influenced by the electrical interconnections required among the hundreds or thousands of chips they contain. The development of the complex interconnection design scheme is profoundly influenced by the interactions among the component and subassembly designs: modules, printed-circuit boards, cables, connectors, etc. The design scheme is also strongly affected by the constraints imposed by manufacturing process limitations and by environmental factors, such as cooling and corrosion. This paper deals with these interactions and constraints as encountered in the interconnection design of the IBM 3081 system and the design discipline required to deal with them.

Influence on LSI Package Wireability of Via Availability and Wiring Track Accessibility *by J. H. Koch III, W. F. Mikhail, and W. R. Heller, p. 328.* In this paper, experiments are reported which use automatic global and line-packing wiring routines, supplemented by a restricted maze runner, to evaluate the overall influences of several important physical variables upon the wireability of several logic-circuit package types. The logic circuits are contained in subpackages (e.g., modules carrying chips), which are inserted, using pins, into the carrier package in a regular array of holes otherwise available as vias interconnecting the wiring planes. Over a

range of connection counts from several hundred to several thousand, it is found that "overflows" (connections not wired by the program) amounting to as much as 10 or 15% of the wires can be substantially reduced in number by careful design. This can be done by using a sufficient number of programmable vias (greater than one per used pin) and by using a track grid ensuring maximum global track accessibility to all pins, or by a combination of both of these tactics in conjunction with suitable wiring algorithms. Some simple theoretical arguments are given which characterize the design problem in the light of the results.

Lead Reduction Among Combinatorial Logic Circuits *by W. V. Vilkelis, p. 342.* The paper provides a description of the behavior of lead reduction among combinatorial logic circuits. Methods by which one may design the lead reduction architecture for modular packaging schemes are developed. The methods are then applied to the design of the lead reduction architecture of an integrated circuit chip and a nine-chip cell.

Electrical Design of a High Speed Computer Package *by E. E. Davidson, p. 349.* A methodology for optimizing the design of an electrical packaging system for a high speed computer is described. The pertinent parameters are first defined and their sensitivities are derived so that the proper design trade-offs can ultimately be made. From this procedure, a set of rules is generated for driving a computer aided design system. Finally, there is a discussion of design optimization and circuit and package effects on machine performance.

A VLSI Bipolar Metallization Design with Three-Level Wiring and Area Array Solder Connections *by L. J. Fried, J. Havas, J. S. Lechaton, J. S. Logan, G. Paal, and P. A. Totta, p. 362.* The ability to interconnect large numbers of integrated silicon devices on a single chip has been greatly aided by a three-level wiring capability and large numbers of solderable input/output terminals on the face of the chip. This paper describes the design and process used to fabricate the interconnections on IBM's most advanced bipolar devices. Among the subjects discussed are thin film metallurgy and contacts, e-beam lithography and associated resist technology, a high temperature lift-off stencil for metal pattern definition, planarized rf sputtered SiO_2 insulation/passivation, the "zero-overlap" via hole innovation, in situ rf sputter cleaning of vias prior to metallization, and area array solder terminals.

Optimization of Indium-Lead Alloys for Controlled Collapse Chip Connection Application *by R. T. Howard, p. 372.* Indium-lead solders are used for IBM controlled collapse chip connections (C-4s) to improve fatigue life in temperature cycling for large chip applications. Using 50% In-Pb alloy, which is expensive, has posed a number of manufacturing and reliability concerns. This paper presents the results of development studies leading to the use of a low-indium solder alloy for C-4 applications. This alloy overcomes all previous concerns while exceeding the fatigue life specification of the high-indium alloy. Also described are the variables and tests used to evaluate C-4 performance of In-Pb alloys over the 5% to 50% range. Results are presented graphically and mathematically to show the improvement obtained with indium-content solders over the conventional tin-lean alloys.

Immersion Wave Soldering Process *by J. R. Getten and R. C. Senger, p. 379.* Immersion wave soldering is a new technique for soldering advanced printed circuit boards. In this process, an assembled and fixtured printed circuit board is immersed in a fluxing fluid and preheated to the soldering temperature. The fluxing fluid is glycerine activated with ethylenediamine tetra-acetic acid (EDTA). After preheating and while still immersed in the fluxing fluid, the fixtured board is passed over a tin-bismuth eutectic (42% Sn, 58% Bi) solder wave. This technique has several advantages over conventional soldering processes, including elimination of solder dross formation, improved control over solder deposition, reduced thermal shock, easier cleaning after soldering, and improved flux effectiveness.

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Preface *by E. J. Galli, p. 399.*

Microprocessor Implementation of Mainframe Processors by Means of Architecture Partitioning *by P. W. Agnew and A. S. Kellerman, p. 401.* The benefits of Large-Scale Integration (LSI) implementations have applied quite naturally to processors with relatively low performances and simple architectures; e.g., the one-chip microprocessors used in personal computers contain several thousand logic gates. Mainframe processors, however, have so far been limited to using logic chips that contain several hundred logic gates. The best use of LSI logic employs microprocessors to keep critical paths on chip, thus keeping pin counts and power dissipations within reasonable limits. Microprocessors have been extensively used to implement peripheral functions, such as I/O device control. However, as of this writing, a single state-of-the-art microprocessor cannot contain a mainframe processor function. Therefore, new machine organizations are needed to use today's state-of-the-art microprocessors to implement a mainframe processor. This paper examines several methods for applying LSI and microprocessors to the design of processors of increasing performance and complexity, and describes a number of specific approaches to microprocessor-based LSI implementation of System/370 processors. The most successful approaches partition the System/370 instruction set into subsets, each of which can be implemented by microcode on a special microprocessor or by programs written for an off-the-shelf microprocessor.

A Microprocessor for Signal Processing, the RSP *by F. Mintzer and A. Peled, p. 413.* Signal processing is a data processing domain that contains a diversity of applications, including speech processing, image processing, radar, sonar,

medical imaging, data communications, seismic processing, and many others. Despite the diversity of the applications, this processing domain has a very structured set of characteristics. These include real-time operation, dominance of arithmetic operations, and well-structured data flows. The Real-Time Signal Processor (RSP) is a microprocessor architecture that was created to exploit these characteristics in order to provide an expeditious and economical way to implement signal processing applications. In this paper, the organization and architecture of the RSP are described. Features of the RSP, such as the instruction pipeline and the fractional fixed-point arithmetic, which exploit the characteristics of signal processing to provide additional computational power, are emphasized. Other features, such as the powerful indexing, the saturation arithmetic, the guard bits, and the double-word-width accumulator, which add much to the processor's versatility and programmability, are also highlighted. The performance of the RSP is illustrated through examples.

Rectangular Transforms for Digital Convolution on the Research Signal Processor *by J. W. Cooley, p. 424.* The Rectangular Transform (RT) method for computing convolutions belongs to a family of Reduced Computational Complexity (RCC) algorithms. Convolution calculations by the RT method were programmed for the Research Signal Processor (RSP) and run on the RSP simulator, giving tabulations of numbers of RSP machine cycles. One of the original objectives was to see how well the original RSP architecture was suited to the RCC algorithms and to be able to make suggestions for possible changes. The results are also intended to demonstrate the efficiency of the RT convolution algorithms on a microprocessor with a limited instruction set and to show how to construct efficient RT programs for digital convolution. All results are given for the original RSP, as it was before the modification which resulted in the Real-time Signal Processor described in another paper in this issue.

Real-Time Signal Processor Software Support *by K. Davies and F. Ris, p. 431.* The Real-Time Signal Processor (RSP) is a microprocessor optimized to provide fast, cost-efficient processing for signal processing applications. In order for the RSP to become fully useful, a complete set of software support tools needed to be developed. The hardware design and software development, which took place between 1978 and 1980, resulted in many architectural features which minimized hardware complexity at the expense of programmability. This paper describes the tools that were developed and the decisions that were involved, and includes hindsight comments on what was done. Particular emphasis is placed on the most interesting aspects of the software development, i.e., how the special architectural features of the RSP were handled to make the overall hardware/software system more programmable.

Common Chip for Use in Disk and Diskette Controllers *by G. L. Dix and M. D. Brown, p. 440.* The advent of LSI technology makes common microprogrammable controllers very cost-effective today. This paper focuses on the application of microcontrollers for disk and diskette control functions and describes a custom-designed FET chip which is being developed for use in these types of controllers. The architecture, the functional organization, and the physical design of this chip are presented, and the requirement of matching a microcontroller to the application is discussed.

Physical Design of a Custom 16-Bit Microprocessor *by A. Correale, p. 446.* The physical chip design aspects of a 16-bit, single-chip, custom-macro-designed microprocessor are described. This microprocessor represents the IBM System Products Division's highest-density VLSI FET processor design to date. The chip is a complex arrangement of over 6500 VLSI circuits utilizing a state-of-the-art polysilicon-gate HMOS-1 (high-performance MOS) technology. The physical design of this chip required the use of a comprehensive methodology, from conception through completion. The methodology used in the design of the microprocessor was based on a hierarchical approach and is presented in this paper.

Design Considerations for a VLSI Microprocessor *by J. E. Campbell and J. Tahmoush, p. 454.* The machine architecture and design considerations for an interrupt-driven bipolar VLSI Microprocessor are presented. The processor is designed to a complex architecture and includes an integrated channel and a flexible storage interface. Floating-point functions are optional. A 3-ns custom bipolar technology was developed for the microprocessor, resulting in a very high circuit density package. The 50-mm four-chip air-cooled microprocessor module is packaged on a printed-circuit card with associated repowering circuits and high-speed random-access memory. Important design considerations and tradeoffs associated with the development of this machine, within specific cost, performance, reliability, and schedule objectives, are discussed. Various processor design techniques are described which minimize hardware where performance is not critical. A degree of functional parallelism is utilized, as well as timing flexibility, to attain the required performance.

Bipolar Chip Design for a VLSI Microprocessor *by K. F. Mathews and L. P. Lee, p. 464.* In this paper, a pseudo-custom approach to bipolar VLSI chip design is presented, and a hierarchical structure of logic macros assembled from building blocks is described. A strategy of placing the logic macros along with algorithmically designed PLA structures and ROS with a placement aid, and of wiring the placement with an automatic wiring program, is discussed. The paper also focuses on the implementation of this strategy in terms of technology, chip structure, and chip design methodology. In addition, chip statistics are presented and their implications are discussed.

A VLSI Design Verification Strategy *by A. S. Tran, R. A. Forsberg, and J. C. Lee, p. 475.* With the ever-increasing

density, development cost, and turn-around time of VLSI chips it becomes increasingly important to have a design verification methodology which enables first-pass chips to be fully functional. The strategy discussed in this paper exploits the best attributes of the two traditional methods of design verification (i.e., software simulation and hardware modeling). Software simulation was chosen for its capability in the area of delay analysis and early functional checking. An automatically generated nodal-equivalent hardware model was built to provide the vehicle on which exhaustive functional checking could be performed. The model also operated as early user hardware on which functions such as operating systems, I/O adapters, and a floating-point feature could be tested. A technique known as interface emulation was used on certain well-defined subsystems to facilitate a shorter verification schedule through parallel debug efforts.

A Bipolar VLSI Custom Macro Physical Design Verification Strategy *by J. F. McCabe and A. Z. Muszynski, p. 485.* The level of complexity and the turn-around time associated with the development of custom bipolar VLSI chips have defined the need for a highly structured physical and electrical design validation approach which can guarantee fully functional first-pass chips, yet be flexible enough to allow logical and physical designers the latitude necessary to achieve specified cost and performance objectives. This paper describes such a design verification strategy and its implied constraints on chip design. The rationale for comparing the logic equivalence of the high-level logical models to the low-level-device physical models is presented, a description of the hierarchical logical-to-physical and electrical checking is given, and its impact on cost and complexity is examined.

Plant Automation in a Structured Distributed System Environment *by N. C. Mescia and C. D. Woods, p. 497.* As VLSI technology evolves, miniaturization demands more sophisticated tools, instruments, and controls to manufacture the VLSI components. IBM's facility at East Fishkill, New York, has the responsibility for the development and manufacture of semiconductor products used in IBM data systems. This requires a sophisticated set of processes, inspections, and tests operating as a fully integrated system. In this paper, the design and implementation of a hierarchical distributed system for manufacturing control of integrated electronic components are described. The implementation includes distributed data bases and inter-level decoupling to ensure 24-hour manufacturing capabilities. Reasons for the choice of the processors used at various levels in the hierarchical network, and the communications required between them, are discussed.

Construction of Bounded Delay Codes for Discrete Noiseless Channels *by P. A. Franaszek, p. 506.* Algorithms are described for constructing synchronous (fixed rate) codes for discrete noiseless channels where the constraints can be modeled by finite state machines. The methods yield two classes of codes with minimum delay or look-ahead.

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Semiconductor Manufacturing Technology at IBM *by H. Carre, R. H. Doxtator, and M. C. Duffy, p. 528.* IBM's current semiconductor manufacturing processes are summarized. Briefly outlined are highlights of salient features of semiconductor manufacturing that established IBM leadership and direction for embarking on VLSI production. Some of these features are taken from papers already published; others are from articles in this issue of the IBM Journal of Research and Development ranging from silicon crystal growth through quality control and automated logistics and dispositioning of tested product.

Evolution and Accomplishments of VLSI Yield Management at IBM *by C. H. Stapper, P. P. Castrucci, R. A. Maeder, W. E. Rowe, and R. A. Verhelst, p. 532.* The methods developed at IBM to manage and improve the yield of some of its newer FET semiconductor products are described. A number of visual inspection and electric monitoring techniques have evolved since discrete semiconductors were manufactured. The data obtained with these techniques are used in self-checking yield models to give the relative yields for all the yield components. The results are applied not only to day-to-day control of the manufacturing lines, but also in the long-range forecasting and planning of future semiconductor integrated circuit products. An example is given comparing the actual and planned yield of a 64K-bit random access memory chip as a function of time. The results show the yield enhancement that was obtained with redundant circuits and additionally with the use of partially functional products. Another example shows the decrease in fault levels over a span of more than ten years.

Oxygen Incorporation and Precipitation in Czochralski-Grown Silicon *by A. Murgai, W. J. Patrick, J. Combronde, and J. C. Felix, p. 546.* Oxygen incorporation is examined for growth of large-diameter (80–130 mm) silicon single crystals by the Czochralski method. The primary growth parameters affecting the oxygen concentration in the crystals are shown to be the crystal-melt interface position within the hot zone and the rate of crucible rotation used. Tight control of the oxygen concentration [±1.5 parts per million atomic (ppma) in the range of 25–40 ppma (ASTM)] has been reproducibly attained by programmed variation of these growth parameters. The attainable oxygen concentrations may be extended over a wider range (20–45 ppma) through slight modifications of the hot zones. Wafers from the uniform-oxygen-concentration crystals are subjected to single-step and two-step annealing procedures (700–1100°C) for oxygen precipitation studies. The rate of precipitation is shown to depend on the initial oxygen content and on the number of initially unpopulated nucleation sites present.

Metrology in Mask Manufacturing *by H. R. Rottmann, p. 553.* A major source of registration failure in microlithography was found to be due to variations in optical field sizes defined by the dies, caused by unsatisfactory focus control. Two methods for determining variations in optical field sizes are described. Both allow measurements of selected registration errors with an uncertainty of ±0.01 μm (1 σ) under manufacturing conditions using commercially available measuring microscopes. The long-term registration stability of stepped-mask exposure systems was also investigated. It is concluded that maintenance of registration over long periods of time can be improved through accurate focus control along the optical axis. Finally, it is suggested that no single set of measurements at one point in time can completely characterize a microlithographic system. Periodic monitoring of key measurable parameters during use is advisable.

Feature Size Control in IC Manufacturing *by P. Frasch and K. H. Saremski, p. 561.* Until recently, the ever-increasing demand for higher device density in integrated-circuit (IC) designs has been satisfied mainly through device and circuit design ingenuity, increased chip size, and dimensional reduction. To keep pace with dimensional reduction, control of dimensional variations has assumed a more significant role. New IC designs are very dense and performance-oriented, requiring 2-μm lithography ground rules with less than ±0.2-μm variations in circuit-feature dimensions at 3σ. Such small variations are difficult to detect and control with the present-day routine in-line-inspection optical tools. In this article, we present a description of the primary causes of dimensional variations in a typical manufacturing environment and proposals for their control.

Electron-Beam Proximity Printing—A New High-Speed Lithography Method for Submicron Structures *by H. Bohlen, J. Greschner, J. Keyser, W. Kulcke, and P. Nehmiz, p. 568.* A laboratory prototype of an electron-beam proximity printer is described which shadow-projects patterns of chip-size transmission masks onto wafers. Electron-beam transmission masks with physical holes at transparent areas have been fabricated with the smallest structures down to 0.3 μm. Experiments to replicate mask patterns were directed at demonstrating the applicability of this lithographic method to high-speed printing of repetitive patterns on wafers. Linewidth resolution and positional accuracy, as well as exposure speed, meet the requirements for micron and submicron lithography.

Optimization of Plasma Processing for Silicon-Gate FET Manufacturing Applications *by A. S. Bergendahl, S. F. Bergeron, and D. L. Harmon, p. 580.* The development and implementation of plasma processing techniques for silicon-gate FET manufacturing applications is described. Process requirements are discussed for the stripping of photoresist and the isotropic etching of thin films. A systematic approach for the optimization of these processes, involving the use of statistically designed multiparametric experimentation (MPE), is presented. This approach, in combination with the use of response-surface analysis techniques, is illustrated by examples of its application to typical processing problems. In addition, the multiparametric optimization of anisotropic etching is presented for potential plasma processing enhancements.

The Mechanism of Single-Step Liftoff with Chlorobenzene in a Diazo-Type Resist *by R. M. Halverson, M. W. MacIntyre, and W. T. Motsiff, p. 590.* The mechanism of the chlorobenzene single-step liftoff process is defined. The chlorobenzene penetrates to some depth into the resist film during the soaking cycle, extracting residual casting solvent and low-molecular-weight resin species. The chlorobenzene is subsequently removed by a rinse cycle. The penetrated layer of resist develops at a slower rate than the underlying bulk resist, producing the liftoff structure.

Process Control of the Chlorobenzene Single-Step Liftoff Process with a Diazo-Type Resist *by G. G. Collins and C. W. Halsted, p. 596.* Introduction of the single-step chlorobenzene liftoff process using a diazo-type resist to manufacturing lines produced problems not encountered during development and pilot-line work. Variances in the structure of the photoresist liftoff image are the result of complex interactions among exposure, chlorobenzene soaking, development, and post-application baking conditions. Effects produced by these variables can be controlled by monitoring the linewidth, overhang, and height of the liftoff resist structure using a scanning electron microscope (SEM). Loss of resist thickness during the chlorobenzene soak is used instead of penetration, as measured on SEM photographs, to monitor the soaking process. Data are presented on the creation and stability of the overhang structure, the process controls required to achieve that stability, and the interactions among the process variables. The process, as practiced in a manufacturing mode, was found to have greatest reproducibility at low exposure, with a combination of long soaking times and high post-application baking temperatures.

Semiconductor Final Test Logistics and Product Dispositioning Systems *by R. M. Burgess, K. B. Koens, and E. M. Pignetti, Jr., p. 605.* As product lines at the IBM East Fishkill plant have expanded in the last few years, and as the number of technologies and semiconductor wafer and module volumes have increased, more sophisticated software systems were introduced which not only drove test times downward, but also reduced the development time previously required to accommodate testing new technologies. This paper discusses two such systems developed for the bipolar semiconductor line. They are a final test logistics system which provides for computerized tracking of each device in the production line through both testing and diagnostic analysis, and an automatic product dispositioning system which immediately identifies shippable product batches after flow through the test sector or schedules the batches for additional diagnostic analysis.

Quality and Reliability Assurance Systems in IBM Semiconductor Manufacturing *by E. H. Melan, R. T. Curtis, J. K. Ho, J. G. Koens, and G. A. Snyder, p. 613.* Soon after semiconductor manufacturing began it was realized that classical process control techniques were needed for the control of quality, reliability, and yield. The discovery and control of yield, quality, and reliability detractors have been pursued continually by IBM manufacturing engineers ever since, and the resulting evolution of process control techniques has grown into a highly disciplined state. Inferential methods were added later to augment the classic techniques. This paper, in addition to providing a brief overview of semiconductor manufacturing control techniques and placing them into historical perspective, discusses a method of feed-forward control based on statistical distributions which is used in the VLSI FET memory device line. This is followed by a description of a process profile technique which is used in bipolar logic manufacturing. The importance of the system aspects in both techniques is emphasized.

Regenerative Simulation of Networks of Queues with General Service Times: Passage Through Subnetworks *by G. S. Shedler and J. Southard, p. 625.* A linear "job stack," an enumeration by service center and job class of all the jobs, is an appropriate state vector for simulation of closed networks of queues with priorities among job classes. Using a representation of the job stack process as an irreducible generalized semi-Markov process, we develop a regenerative simulation method for passage times in networks with general service times. Our estimation procedure avoids Cox-phase representation of general service time distributions and is applicable to networks with "single states" for passage times. Based on a single simulation run, the procedure provides point estimates and confidence intervals for characteristics of limiting passage times.

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Document Analysis System *by K. Y. Wong, R. G. Casey, and F. M. Wahl, p. 647.* This paper outlines the requirements and components for a proposed Document Analysis System, which assists a user in encoding printed documents for computer processing. Several critical functions have been investigated and the technical approaches are discussed. The first is the segmentation and classification of digitized printed documents into regions of text and images. A nonlinear, run-length smoothing algorithm has been used for this purpose. By using the regular features of text lines, a linear adaptive classification scheme discriminates text regions from others. The second technique studied is an adaptive approach to the recognition of the hundreds of font styles and sizes that can occur on printed documents. A preclassifier is constructed during the input process and used to speed up a well-known pattern-matching method for clustering characters from an arbitrary print source into a small sample of prototypes. Experimental results are included.

Automatic Scaling of Digital Print Fonts *by R. G. Casey, T. D. Friedman, and K. Y. Wong, p. 657.* New raster-based printers form character patterns using carefully designed matrices of dots. It is desirable to be able to use fonts designed for one printer on a different machine, but to do so the dot matrix patterns should first be scaled to the second printer's resolution. If the scaling is carried out as a simple interpolation, however, severe degradation in the appearance of the characters may occur. A new algorithm reduces such degradation by recognizing attributes associated with print character quality in the original patterns and then correcting the scaled patterns in order to maintain those attributes. Attributes that are detected and preserved during scaling include local and global symmetries, stroke width, sharpness of corners, and smoothness of contour. The method has been used both to scale low-resolution fonts to a finer representation and to reduce the scale of high-resolution photocomposer fonts for output on an office-type printer.

Analysis of Linear Interpolation Schemes for Bi-Level Image Applications *by I. E. Abdou and K. Y. Wong, p. 667.* In the office, it is often necessary to scan a picture at a certain resolution and then reproduce it at a different (usually higher) resolution. This conversion can be achieved by interpolating the scanned signal between the sample intervals. This paper discusses a class of linear interpolating methods based on resampling polynomial functions. In addition, we introduce new methods to compare the performance of these interpolating schemes. The signal models used are one-dimensional step and pulse functions. These bi-level models are sufficient to describe many black/white documents. The performance of the linear interpolators is determined by evaluating their accuracy in reconstructing the original bi-level signal. The analysis considers the effects of the coarse scan and fine print intervals as well as the quantization effects. Experiments using the IEEE facsimile chart as input verify the analytical findings. The results show the advantage of using odd-order polynomials, such as the first order and TRW cubic. Also, we discuss the relationship between the interpolating ratio and the number of quantization levels needed to represent the scanned signal.

Word Autocorrelation Redundancy Match (WARM) Technology *by N. F. Brickman and W. S. Rosenbaum, p. 681.* Word Autocorrelation Redundancy Match (WARM) is an intelligent facsimile technology which compresses the image of textual documents at nominally 145:1 by use of complex symbol matching on both the word and character level. At the word level, the complex symbol match rate is enhanced by the redundancy of the word image. This creates a unique image compression capability that allows a document to be scanned for the 150 most common words, which make up roughly 50% of the text by usage, and upon their match the words are replaced for storage/transmission by a word identification number. The remaining text is scanned to achieve compaction at the character level and compared to both a previously stored library and a dynamically built library of complex symbol

(character) shapes. Applying the complex symbol matching approach at both the word and character levels results in greater efficiency than is achievable by state of the art CCITT methods.

Digital Halftoning of Images *by D. Anastassiou and K. S. Pennington, p. 687.* Most printers and some display devices are bilevel (black or white) and therefore not capable of reproducing continuous tone pictures. Digital halftoning algorithms transform digital gray scale images into bilevel ones which give the appearance of containing various shades of gray. A halftoning algorithm is presented in which novel concepts are combined resulting in an output image in which moiré patterns are suppressed and, at the same time, the edges are enhanced. Various other artifacts associated with the halftoning process, such as contouring due to coarse quantization or to textural changes, are also absent from the output images in the proposed scheme. The algorithm separates the image into many small clusters which are processed independently and, therefore, it is capable of parallel implementation.

An Improved Segmentation and Coding Algorithm for Binary and Nonbinary Images *by P.-E. Danielsson, p. 698.* This paper presents a new segmentation and coding algorithm for nonbinary images. The algorithm performs contour coding of regions of equally valued and connected pixels. It consists of two distinct phases: raster scanning and border following. In this sense it is similar to algorithms presented by Kruse. However, the algorithm of this paper is considerably improved since it correctly segments truly nonbinary images. The basic idea of the algorithm is to "coat" (color, label) the borders (the cracks) between the regions from both sides in two separate border-following procedures called island following and object following. Thus, all adjacencies between the objects are systematically explored and noted. Furthermore, the raster scanner, which exhaustively searches the image for new regions, can easily determine from existing/nonexisting coating which boundaries have been traced out and which have not. The algorithm can be considerably simplified for the binary image case.

Reduced Data Re-Order Complexity Properties of Polynomial Transform 2D Convolution and Fourier Transform Methods *by T. A. Kriz, p. 708.* This paper presents new results concerning the matrix data re-order requirements of polynomial-transform-based 2D convolution and 2D Fourier Transform methods which can be employed in digital processing of images and other 2D problems. The results indicate that several power-of-2 length-modified ring polynomial transform methods developed by Nussbaumer allow the total avoidance of the row-column matrix transpose commonly encountered in other algorithmic approaches, while also providing a number of other computational advantages. It is demonstrated that this property can be the source of significantly improved throughput on a number of existing data processing structures. An execution time comparison with an efficient Fast Fourier Transform algorithm base is made assuming the use of general register architecture and array processor units. It is also assumed that one makes use of recently developed efficient matrix transpose methods by Eklundh and Ari to support 2D FFT data re-order requirements. These comparisons demonstrate a two to four times throughput improvement for the use of the polynomial transform method in place of the 2D FFT approach to circularly convolve or generate 2D Fourier transforms for large 2D fields in the range 1024×1024 to 8192×8192.

Importance of Higher-Order Components to Multispectral Classification *by J. V. Dave, R. Bernstein, and H. G. Kolsky, p. 715.* A Landsat multispectral image was combined with the corresponding digital terrain elevation data to study several information extraction procedures. Principal component and limited multispectral classification procedures were conducted on 1024×1024 four-band Landsat and five-band (Landsat plus terrain data) images, and color composites as well as quantitative information were generated. Selected results of this preliminary investigation confirm the usefulness of the principal component analysis in a qualitative presentation of the multi-band data and its association with a significant reduction in dimensionality. However, unlike some other investigators, we found that the full dimensionality must be retained when the information content of the data has to be preserved quantitatively.

Some Experiments in Image Vectorization *by J. Jimenez and J. L. Navalon, p. 724.* The application of vectorization algorithms to digital images derived from natural scenes is discussed. It is argued that the fractal nature of these scenes precludes some of the savings in storage expected from vector over raster representation, although considerable savings still result. Experimental results are given. Algorithms for contour following, line thinning, and polygonal approximation well adapted to complex images are presented. Finally, the Map Manipulation System, an experimental program package designed to explore the interaction between vector and raster information, is described briefly.

Digital Multi-Image Analysis: Application to the Quantification of Rock Microfractography *by L. Montoto, p. 735.* The microfissuration of a rock sample is analyzed using a multi-image formed of micrographs which were obtained under fluorescence and polarizing microscopy of the same sample area. Image analysis methods are applied to obtain descriptions of each type of picture, one showing the microfissure network and the other the texture of the rock. Descriptions in the form of tables of coordinates are used to quantify the features contained in the pictures. Finally, it is shown that relationships between these descriptions can result in the integration of the available information, providing more knowledge about microfissuration in the sample, including characterization and quantification of microcrack types according to their position with respect to the texture of the rock.

Backscatter and Attenuation Imaging from Ultrasonic Scanning in Medicine *by E. J. Farrell, p. 746.* Images of backscatter, attenuation, and frequency dependence of attenuation are obtained based on a three-parameter model and computation techniques described in this paper. There are several critical sources of error: backscatter speckle, beamwidth distortion, and cross-coupling artifacts between attenuation and backscatter. An iterative method of imaging and filtering is developed which effectively reduces these errors. Stability of the numerical solution involving the large number of unknowns is obtained by image iteration as opposed to parameter iteration along individual transmitter rays. This method incorporates three basic functional aspects: (1) multiple scans to reduce speckle, beamwidth distortions, and certain cross-coupling artifacts, (2) pre-image filtering to decrease beam distortions and post-image filtering to reduce cross-coupling artifacts, and (3) proper sequencing of image reconstruction and filtering. Backscatter images formed by this image iteration method are significantly superior to standard B-scan images. Further, the image iteration method yields three images of the same scan field. The present investigation is based on simulated echo data from cyst-like and complex targets.

An Algorithm for Separating Patterns by Ellipsoids *by E. R. Barnes, p. 759.* We give an algorithm for finding the ellipsoid of least volume containing a set of points in a finite-dimensional Euclidean space. Such ellipsoids have been proposed for separating patterns in a feature space.

Cursive Script Recognition by Elastic Matching *by C. C. Tappert, p. 765.* Dynamic programming has been found useful for performing nonlinear time warping for matching patterns in automatic speech recognition. Here, this technique is applied to the problem of recognizing cursive script. The parameters used in the matching are derived from time sequences of x-y coordinate data of words handwritten on an electronic tablet. Chosen for their properties of invariance with respect to size and translation of the writing, these parameters are found particularly suitable for the elastic matching technique. A salient feature of the recognition system is the establishment, in a training procedure, of prototypes by each writer using the system. In this manner, the system is tailored to the user. Processing is performed on a word-by-word basis after the writing is separated into words. Using prototypes for each letter, the matching procedure allows any letter to follow any letter and finds the letter sequence which best fits the unknown word. A major advantage of this procedure is that it combines letter segmentation and recognition in one operation by, in essence, evaluating recognition at all possible segmentations, thus avoiding the usual segmentation-then-recognition philosophy. Results on cursive writing are presented where the alphabet is restricted to the lower-case letters. Letter recognition accuracy is over 95 percent for each of three writers.

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Product Quality Level Monitoring and Control for Logic Chips and Modules *by D. S. Cleverley, p. 4.* In the manufacture of chips and modules, it is important to minimize defects in order to maximize quality levels and product reliability at each level of product assembly (chips, module, card, system). These objectives are best achieved by controlling defects through manufacturing process controls and testing at the lowest possible level of assembly. Defective product remaining after test and inspection must be repaired or discarded. The ability to detect and reduce or eliminate these defects is crucial to ensuring maximum product quality. The amount of such defective product is typically described quantitatively in terms of statistical sampling plans. The problem with such approaches is that the absolute defect level is imprecisely defined. This paper defines an absolute number for such product defects, which we will call "product quality level" (PQL). PQL categories found in logic chips and modules after completion of electrical testing are described and a methodology for the monitoring and control of the PQL in chips is presented. The impact of chip defects on module, card, and system performances is discussed with the aid of examples. By using the described comprehensive design, process control, testing, and user-feedback approach at each assembly level, final product can be manufactured with the lowest possible level of defects that must then be repaired at the machine level.

Multi-Layer Ceramics Manufacturing *by W. G. Burger and C. W. Weigel, p. 11.* Multi-layer ceramics (MLC) is an advanced packaging technology developed by IBM and used in the IBM 4300 and IBM 3081 processor models to significantly improve the module circuit density, reliability, and performance over those of previous packages. A key element in this package is the MLC substrate, which is capable of supporting more than 100 semiconductor chips in some design uses. The MLC manufacturing facility requires that sophisticated processing and inspection/test equipment operate within a hierarchically integrated system. This paper provides an overview of the manufacturing process that has been implemented to satisfy the high-volume manufacturing needs of this complex package. It also describes the data handling systems.

Precise Numerical Control for the Thermal Conduction Module *by M. A. Sanborn, p. 20.* Automated manufacturing processes have been developed and put into practice for the high-volume production of the thermal conduction module, the high-density circuit package used in the IBM 3081 processor models. The very precise work required on the ceramic surface required the solution of many problems. The small but significant residual distortions (warpage) which resulted from firing the multi-layer ceramic substrates made it difficult to locate tooling precisely for subsequent processes. A unique scheme for measuring the module and precalculating numerical control data has made it possible to achieve full automation. The nature of the problem, the attempts at a simple solution, and the algorithms finally used for numerical control data calculation are presented.

Multi-Chip Module Test and Diagnostic Methodology *by J. J. Curtin and J. A. Waicukauski, p. 27.* The development of a manufacturing test and diagnostic methodology for multi-chip modules as used in the IBM 4300 processor models involves determining the most attractive compromise among a number of conflicting factors: a) high test coverage, b) high diagnostic resolution, c) test generation, d) test equipment, and e) test application and diagnosis. This paper describes a set of solutions which were developed to create a high-volume, low-cost manufacturing test operation for the product in question. This paper examines the role of the testing methodology in productivity and product quality, details the diagnostic approach chosen, and provides an example of the overall manufacturing system performance achieved by analyzing a large module production sample.

The LT1280 for Through-the-Pins Testing of the Thermal Conduction Module *by R. L. Pierson and T. B. Williams, p. 35.* Testing the thermal conduction module (TCM), the high-density field-replaceable unit (FRU) used in the IBM 3081 processor models, and diagnosing the faults encountered to a minimal repairable set of entities posed a new problem for the IBM engineers. The requirement and the economic necessity of thoroughly exercising the entire TCM logic and random access memory (RAM) array structure through the input/output pins of the TCM are discussed. This is followed by a description of the test system alternatives and the LT1280 [logic tester having 1280 input/output (I/O) pins] as the selected TCM manufacturing test system. The TCM logic density and high I/O count required new concepts of test system organization, size, and complexity to achieve a test and diagnostic system with high flexibility and high throughput capability.

Failure Diagnosis on the LT1280 *by P. L. Barry, p. 41.* The high-density circuitry and I/O pin population of the thermal conduction module (TCM), the VLSI package used in the IBM 3081 processor models, dictates that there be a precise and cost-effective method of detecting and diagnosing TCM defects. This paper describes the challenge faced in testing the logic and random access memories of the TCM and the diagnostic approach used in the LT1280 test system for testing the TCM through its I/O pins. The generation and application of tests are discussed, and the automated multiple-defect diagnostic (AMDD) algorithm is presented in detail.

Computer-Controlled Optical Testing of High-Density Printed-Circuit Boards *by M. A. West, S. M. DeFoster, E. C. Baldwin, and R. A. Ziegler, p. 50.* The increased densities of multi-layer printed-circuit boards have required development of unique approaches to product testing. An optical automatic inspection system developed to test interplanes of the printed-circuit board used in the IBM 3081

processor (TCM board) is described. This system scans the features of the product and locates surface defects of 25.4 μm (1 mil) or larger through changes in reflectivity. It is capable of finding over 90% of the errors on subtractively plated printed-circuit interplanes, as well as shorts and opens of 50 μm or more on glass masters of printed-circuit boards. Alternative approaches to the inspection problem are discussed, together with the technical trade-offs which were made that led to the final system configuration. The tester theory and some hardware/software trade-offs are also covered.

A Model for the Prediction of Assembly, Rework, and Test Yields *by B. J. Dooley, p. 59.* The increase in density and complexity of computer components used as field-replaceable units of the IBM 3081 processors has required more sophisticated and capital-intense manufacturing and test lines than heretofore seen. To help in the manufacturing planning effort, a simulation model based on the concepts described in this paper was implemented as a means for studying the behavior of different assembly/test methodologies and to predict the throughput capabilities of various manufacturing configurations. By adopting a different simulation philosophy, the model was greatly simplified, and by taking advantage of the matrix processing features of APL, modeling changes required due to procedure or test-equipment changes could easily be implemented. This paper reviews the philosophy of the simulation of computer part assembly, takes a new look at modeling, and describes the architectural concepts embodied in the implementing program. It also details some of the more important concepts needed to complete the simulator.

Technologies for Network Architecture and Implementation *by F. D. Smith and C. H. West, p. 68.* Systems Network Architecture (SNA) provides a framework for constructing networks of distributed processors and terminals. This paper discusses some of the fundamental properties of network architectures such as SNA, and the evolution of formal descriptive methods that provide precise, complete definitions of the architecture. This has culminated in the development of a programming language, Format and Protocol Language (FAPL), tailored for programming a reference model or meta-implementation of an SNA node. In this form, the architecture specification is itself machine-executable. This property has led to new software technologies that improve quality and productivity in the processes for developing a network architecture and the product implementations derived from it. Automated protocol validation provides the tool necessary to ensure a correct and internally consistent definition of the architecture. This definition can then be used as a standard for testing products to determine compliance with the architecture. Direct implementation of network software by compiling the meta-implementation program is another emerging technology. This paper reviews the current state of work in these areas.

***IBM Journal of Research and Development*: Information for Authors** *by H. Freitag, p. 89.* This paper combines background information about the *IBM Journal of Research and Development* with guidelines for the preparation of *Journal* manuscripts. The purpose is to acquaint authors with the *Journal* as a primary, professional publication and to present suggestions to ease the work of author and editor in preparing clear, concise, and useful manuscripts.

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Arithmetic Codes for Constrained Channels *by G. N. N. Martin, G. G. Langdon, Jr., and S. J. P. Todd, p. 94.* Arithmetic codes have been studied in the context of *compression coding*, i.e., transformations to code strings which take up less storage space or require less transmission time over a communications link. Another application of coding theory is that of noiseless *channel coding*, where constraints on strings in the channel symbol alphabet prevent an obvious mapping of data strings to channel strings. An interesting duality exists between compression coding and channel coding. The *source* alphabet and *code* alphabet of a compression system correspond, respectively, to the *channel* alphabet and *data* alphabet of a constrained channel system. The decodability criterion of compression codes corresponds to the representability criterion of constrained channel codes, the generalized Kraft Inequality has a dual inequality due to the senior author.

A General Fixed Rate Arithmetic Coding Method for Constrained Channels *by S. J. P. Todd, G. G. Langdon, Jr., and G. N. N. Martin, p. 107.* This paper extends the result of earlier work on the application of arithmetic codes to the constrained channel problem. We specifically present a general length-based fixed rate implementation technique which performs the arithmetic coding recursions during each channel time unit. This technique is superior to an earlier unpublished code for general constrained channels. The approach permits the design of codes for sophisticated channel constraints.

Design Issues and Architecture of HACIENDA, an Experimental Image Processing System *by P. Franchi, J. Gonzalez, P. Mantey, C. Paoli, A. Parolo, and J. Simmons, p. 116.* The paper provides the rationale for the architecture and design of a color image display and processing system called HACIENDA. The system was heavily influenced by one of its most important intended applications, the processing of LANDSAT data, including that to be provided by LANDSAT D. Also considered in the paper are the trade-offs involved in making the system suitable for a broader range of image processing work without unduly adding to cost or complexity.

The Perceptual Color Space of Digital Image Display Terminals *by A. Santisteban, p. 127.* The geometric properties of the set of colors that can be displayed on the TV

monitor of a digital image processing terminal are discussed in the framework of the Commission Internationale de l'Eclairage (CIE) 1976 ($L^* u^* v^*$) color space. Quantitative results are presented for the HACIENDA image processing system. The use of lightness, chroma, and hue angle for the representation of multi-band images is briefly discussed.

A Fair Carpool Scheduling Algorithm *by R. Fagin and J. H. Williams, p. 133.* We present a simple carpool scheduling algorithm in which no penalty is assessed to a carpool member who does not ride on any given day. The algorithm is shown to be fair, in a certain reasonable sense. The amount of bookkeeping grows only linearly with the number of carpool members.

A "Zero-Time" VLSI Sorter *by G. Miranker, L. Tang, and C.-K. Wong, p. 140.* A hardware sorter suitable for VLSI implementation is proposed. It operates in a parallel and pipelined fashion, with the actual sorting time absorbed by the input/output time. A detailed VLSI implementation is described which has a very favorable device count compared to existing static RAM.

OYSTER: A Study of Integrated Circuits as Three-Dimensional Structures *by G. M. Koppelman and M. A. Wesley, p. 149.* This paper presents a design for a software system (OYSTER) for the parametric simulation and analysis of the fabrication steps of very large scale integrated circuit devices. The system is based on a solid geometric modeling approach in which the component parts of an integrated circuit are represented at any step as three-dimensional solid objects in a geometric data base. The simulation of a fabrication step transforms the data base representation of the geometry and the relations among component parts from their state before the step to their state after the step. At any step, and particularly after the final step, the component parts may be analyzed automatically to determine geometric, mechanical, thermal, and electrical properties. Statistical effects may be incorporated to allow investigation of alignment tolerance build-up and yield. A prototype study is described in which an existing geometric modeling system is used to transform a set of planar masks for an FET device through 28 process steps into 3-D models which are used to compute device capacitances.

Fractal Nature of Software-Cache Interaction *by J. Voldman, B. Mandelbrot, L. W. Hoevel, J. Knight, and P. Rosenfeld, p. 164.* This paper uses fractals to model the clustering of cache misses. The clustering of cache misses can be quantified by a single number analog to a fractional dimension, and we are intrigued by the possibility that this number can be used as a measure of software complexity. The essential intuition is that cache misses are a direct reflection of changes in locality of reference, and that complex software requires more frequent (and larger) changes in this locality than simple software. The cluster dimension provides a measure (and perhaps the basis for a model) of the intrinsic differences between workloads. In this paper, we focus on cache miss activity as a discriminate between interactive and batch environments.

Axisymmetric Motion of Radially Polarized Piezoelectric Cylinders Used in Ink Jet Printing *by N. Bugdayci, D. B. Bogy, and F. E. Talke, p. 171.* An analysis of the low frequency response of piezoelectric squeeze tubes used in drop-on-demand ink jet printing is carried out. The displacements at inner and outer boundaries are determined as a function of voltage and fluid pressure. The results are used to obtain fluid pressure per applied voltage as a function of inner and outer radius. Numerical computations are carried out for PZT-5H, and results are presented in graphical form which can be used to optimize design dimensions. The effect of finite electrode thickness is also studied.

An Improved Regional Correlation Algorithm for Signature Verification Which Permits Small Speed Changes Between Handwriting Segments *by J. S. Lew, p. 181.* If two nearly coincident accelerometers on a pen axis measure orthogonal acceleration components perpendicular to this axis, then the *regional correlation algorithm* for signature verification divides these data into plausible segments, it compares each segment with a corresponding reference, and it combines the results into a global similarity index. The presently used intersegment distance permits certain natural data transformations: (1) translating a segment by small integer multiples of the sampling interval; (2) moving the pen with uniformly larger amplitude throughout a segment; and (3) rotating the pen about its axis between any two segments. We propose a new intersegment distance which permits further natural transformations: (4) translating a segment by a fraction of the sampling interval; and (5) writing at slightly different uniform speed within each segment. The new distance, like the old one, is the minimum of a certain function. We describe an algorithm which computes this minimum.

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System/370 Extended Architecture: Design Considerations *by A. Padegs, p. 198.* This paper reviews the overall objectives and the design considerations that led to the System/370 Extended Architecture (370-XA). It presents an overview of the differences between the System/370 and 370-XA architectures and summarizes all architectural extensions, deletions, and changes. Then it describes in more detail the extensions for interpretive execution, 31-bit addressing, protection, tracing, inter-CPU communications, and extended-precision floating-point division.

System/370 Extended Architecture: The Channel Subsystem *by R. L. Cormier, R. J. Dugan, and R. R. Guyette, p. 206.* The 370-XA channel subsystem architecture represents a significant extension of the corresponding System/370 architecture. This paper examines the need for

these extensions, discusses the important features and facilities of the new architecture, and provides comparisons with its predecessor, the System/370 channel architecture. It also describes, from an operational viewpoint, how these new concepts affect I/O processing and how they relate to the current trend toward using multiple CPUs, increasing CPU execution speed, and increasing the number of I/O attachments.

A Fault-Tolerant System Architecture for Navy Applications *by W. T. Comfort, p. 219.* This paper describes the architecture of a computer system, being designed and built for the U.S. Navy, that is expected to be the standard Navy shipboard computer for the next twenty years or so. It has a requirement for very high system reliability, which is addressed by a multiprocessor system configuration that can recover dynamically from hardware faults and support on-line repair of failed hardware elements. Successfully accomplishing this requires various types of redundant hardware elements and special system architecture features, as well as intelligent fault-recovery software. This also requires that the application programs be designed to participate fully in the recovery and reconfiguration process. This paper presents the overall system architecture and discusses a number of significant new features designed to support fault-tolerant operation, including a duplex control bus, a computer interconnection system, a technique for remote diagnostics, a single-button maintenance procedure, and special fault-handling software.

The 801 Minicomputer *by G. Radin, p. 237.* This paper provides an overview of an experimental system developed at the IBM Thomas J. Watson Research Center. It consists of a running hardware prototype, a control program, and an optimizing compiler. The basic concepts underlying the system are discussed, as are the performance characteristics of the prototype. In particular, three principles are examined: (1) system orientation towards the pervasive use of high-level language programming and a sophisticated compiler, (2) a primitive instruction set which can be completely hard-wired, and (3) storage hierarchy and I/O organization to enable the CPU to execute an instruction at almost every cycle.

Integration of Machine Organization and Control Program Design—Review and Direction *by G. S. Rao and P. L. Rosenfeld, p. 247.* This paper discusses the relationship between machine organization and control program design in high-end commercial computer systems. The criterion is cost/performance, subject to achieving an acceptable performance level. A brief discussion of the environment expected for the design and operation of high-end commercial computer systems is outlined, followed by a discussion of machine organization techniques which are classified and reviewed to permit a qualitative evaluation of the degree to which control program intent is exploited in machine organization. The thesis is developed next, using a hierarchical model which illustrates the contention that architecture has acted as a barrier to communication between the control program and machine organization. Examples of techniques that exploit knowledge of the intent of the control program and comments on the methodology that might be used to investigate such techniques follow. Directions for further research are then proposed.

Documenting a Computer Architecture *by R. E. Wright, p. 257.* The documentation of a computer architecture requires that special conditions be satisfied in its preparation to ensure exactness, consistency, and completeness. One group in IBM, Central Systems Architecture, has spent many years refining procedures for producing quality documentation of this type, most notably for the System/370 architecture and the System/370 Extended Architecture (370-XA). This paper describes the steps this group performs in documenting a computer architecture, the requirements identified for the finished description, and the procedures followed to satisfy those requirements.

Random-Pattern Coverage Enhancement and Diagnosis for LSSD Logic Self-Test *by E. B. Eichelberger and E. Lindbloom, p. 265.* Embedded linear feedback shift registers can be used for logic component self-test. The issue of test coverage is addressed by circuit modification, where necessary, of random-pattern-resistant fault nodes. Also given is a procedure that supports net-level diagnosis for structured logic in the presence of random test-pattern generation and signature analysis.

Bounce and Chaotic Motion in Impact Print Hammers *by F. Hendriks, p. 273.* The basis of this paper is a lumped-parameter description of an impact printer actuator of the stored-energy type. All constants necessary to describe the actuator and the ribbon/paper pack are derived from measurements. The equations of motion are integrated both for single- and multiple-current pulse excitation. The numerical results show that for low repetition rates, each impact is distinct and independent, but at higher rates the impacts interact. The interaction manifests itself initially as flight-time and print-force variations: Strict periodicity of the actuator motion is lost, as shown in Poincaré plots for the actuator motion, and randomness sets in. At extremely high repetition rates, the actuator "hangs up" and the backstop no longer participates in the actuator dynamics. During settle-out the actuator motion is extremely sensitive to the timing of the current excitation. This fact can, in principle, be exploited to achieve extremely fast cycle times. However, without knowledge of the state of the actuator, as is commonly the case, this sensitivity is detrimental to print quality.

Digital Simulation of Magnetic Czochralski Flow Under Various Laboratory Conditions for Silicon Growth *by W. E. Langlois and K.-J. Lee, p. 281.* Previous digital simulations have suggested that an axial magnetic field in the 0.1-T (1000-Gs) range can effectively suppress convection in Czochralski growth of silicon. The present paper treats the

matter more quantitatively by investigating the convection in a variety of flow conditions corresponding to typical Czochralski growth of silicon on a laboratory scale.

Large Multi-Layer Panel-Drilling System *by W. R. Wrenner, p. 285.* This paper describes the mechanical, electrical, and control features of an advanced four-station, twelve-spindle, large printed-circuit panel-drilling system. The system was designed as a production tool to produce over 35,000 0.4-mm-diameter holes in a panel containing twenty layers of copper and nineteen layers of epoxy glass. Built around a precision four-station *x-y* positioning system with three motor-driven spindles over each work station, the system includes a minicomputer, a printer, a display station, and a controller/interface station. Drilling parameters, such as infeed, outfeed, top of stroke, bottom of stroke, and spindle revolution rates, are all computer-controlled.

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High-Resolution Carbon-13 NMR of Polymers in the Solid State *by J. R. Lyerla and C. S. Yannoni, p. 302.* This paper reviews the salient features of the methods used for resolution and sensitivity enhancement in ^{13}C NMR spectra of solids. Performance characteristics of the unique variable-temperature cross-polarization magic angle spinning (VT-CPMAS) apparatus developed in our laboratory are given. We present results of structural studies on fluoropolymers using this technique, and discuss the issue of intensities in cross-polarized spectra. In addition, results of an ongoing VT-CPMAS study of polypropylene dynamics are given.

Magic Angle Spinning NMR of Conducting Polymers *by T. C. Clarke, J. C. Scott, and G. B. Street, p. 313.* Because of their typically intractable nature, conducting polymers as a class of materials have proved particularly difficult to characterize by the conventional techniques of polymer analysis. We present here examples of the application of a powerful new tool, cross-polarization magic angle spinning (CPMAS) ^{13}C NMR spectroscopy, to the investigation of the structure and reactions of the conducting polymers polyacetylene and polypyrrole.

Polymer Structure Determination Using Electron Diffraction Techniques *by R. H. Geiss, G. B. Street, W. Volksen, and J. Economy, p. 321.* The crystallographic structure of organic crystals is most commonly studied using x-ray diffraction (XRD) techniques. Unfortunately, rather large crystals, at least 10^6 μm^3, are required for XRD analysis, and it is often quite difficult and sometimes impossible to prepare such large crystals. On the other hand, electron diffraction techniques, although not nearly as precise as XRD, do afford the capability of studying much smaller crystals. The minimum size for electron diffraction is on the order of 10^{-3} μm^3 (0.1 μm^2 area by 0.01 μm thick). Since most polymer crystals are very sensitive to radiation damage caused by the beam in the electron microscope, special precautions must be taken to minimize beam damage to the specimen. Our approach to minimizing radiation damage, while still obtaining usable diffraction data, is described in terms of using the condenser-objective lens optics of the Philips 301 S(TEM) electron microscope. Three examples of the application of electron diffraction structure analysis are given. These include the structures of halogenated polysulfur nitride $(SN)_x$, neutral α,α'-polypyrrole, and poly(p-hydroxybenzoic acid) (PHBA).

Electrochemical Synthesis of Electrically Conducting Polymers from Aromatic Compounds *by J. Bargon, S. Mohmand, and R. J. Waltman, p. 330.* Amorphous, electrically conducting polymeric films can be deposited from acetonitrile solutions of specific aromatic compounds containing an appropriate electrolyte. Free-standing films peeled off a platinum electrode have electrical conductivities σ between 10^{-3} and 1 Ω^{-1}-cm^{-1}. Polymers resembling the better-known polypyrrole have been obtained from benzenoid, nonbenzenoid, and heterocyclic monomers. A few characteristic examples are discussed to highlight the characterization efforts. Also discussed are the chemical investigations which have provided some insight into the mechanism of formation and the structure of these conducting polymers.

Mechanical Properties of Electrochemically Prepared Polypyrrole Films *by A. F. Diaz and B. Hall, p. 342.* The mechanical and conducting properties of free-standing films of polypyrrole toluenesulfonate depend on the preparation conditions. Films prepared in aqueous ethylene glycol solvent mixtures show a variation of two orders of magnitude in the conductivity and of a factor of three in the tensile strength.

Electron Microscopy of Carbon-Loaded Polymers *by V. E. Hanchett and R. H. Geiss, p. 348.* It is very difficult to fully characterize the spatial distribution of particles in carbon-loaded polymers using traditional methods. One approach has been to cross-section the polymers, using ultramicrotomy techniques, to a thickness of 80–100 nm. These sections are then examined in a transmission electron microscope (TEM). Unfortunately, the information on particle dispersion obtained from such images is essentially two-dimensional in nature, and therefore does not lend itself easily to a three-dimensional interpretation. By increasing the thickness of the cross sections to 0.5 μm or more, one is able to utilize stereoscopic imaging techniques and obtain a three-dimensional image of the carbon particle dispersion. In this way, the characteristic dispersion of the carbon particles may be fully evaluated along a particular direction in the polymer film. Examples are given of the three-dimensional analyses of polymer films containing different carbon-particle loadings.

Color Display and Interactive Interpretation of Three-Dimensional Data *by E. J. Farrell, p. 356.* Three-dimensional results from engineering and scientific

computations often involve the display and interpretation of a large volume of complex data. A method is developed for color display of 3D data with several interactive options to facilitate interpretation. The method is based on representing points whose values fall within a specified range as a single hue. An image is formed by overlaying successive 2D frames with increasing hue lightness towards the front. Interactive options to aid interpretations are viewpoint, contour lines, multiple range display, slicing, veiled surfaces, and stereo image pairs. The display method is successfully applied to several types of data. The overall structure and variations of the 3D data are observable, as well as transients which may be overlooked in a large input data set.

Row-by-Row Dynamic Image Analysis of a Matrix of Scanned Points *by D. McAuley, p. 367.* A practical image analysis algorithm is described that incorporates features to permit it to carry out its analysis on a row-by-row basis, in contrast to a full image matrix basis. A significant storage saving is realized, since the total image to be scanned is substantially larger than that used by this method. The dynamic build-up of the image on a scan-by-scan or row-by-row basis is carried out by a series of connectivity, pivot, chain set-up, and chaining algorithms used in conjunction with a dynamic memory allocation strategy.

A Hybrid Optical-Digital Image Processing Method for Surface Inspection *by F. Wahl, S. So, and K. Wong, p. 376.* A hybrid measurement technique is proposed for high-precision surface inspection. The technique uses an interferometer to image microscopic surface defects. In order to quantify the degree of various surface defects, the interferograms are scanned, digitized, and subsequently converted to a binary image by using an adaptive thresholding technique which takes into account the inhomogeneity of the imaging system. A new misalignment measure for binary patterns identifies the "straightness" of the fringe lines. It is shown that the resulting percentages of misaligned picture elements conform fairly well with the degree of various surface defects.

A Processor-Based OCR System *by R. G. Casey and C. R. Jih, p. 386.* A low-cost optical character recognition (OCR) system can be realized by means of a document scanner connected to a CPU through an interface. The interface performs elementary image processing functions, such as noise filtering and thresholding of the video image from the scanner. The processor receives a binary image of the document, formats the image into individual character patterns, and classifies the patterns one-by-one. A CPU implementation is highly flexible and avoids much of the development and manufacturing costs for special-purpose, parallel circuitry typically used in commercial OCR. A processor-based recognition system has been investigated for reading documents printed in fixed-pitch conventional type fonts, such as occur in routine office typing. Novel, efficient methods for tracking a print line, resolving it into individual character patterns, detecting underscores, and eliminating noise have been devised. A previously developed classification technique, based on decision trees, has been extended in order to improve reading accuracy in an environment of considerable character variation, including the possibility that documents in the same font style may be produced using quite different print technologies. The system has been tested on typical office documents, and also on artificial stress documents, obtained from a variety of typewriters.

Image Thresholding for Optical Character Recognition and Other Applications Requiring Character Image Extraction *by J. M. White and G. D. Rohrer, p. 400.* Two new, cost-effective thresholding algorithms for use in extracting binary images of characters from machine- or hand-printed documents are described. The creation of a binary representation from an analog image requires such algorithms to determine whether a point is converted into a binary one because it falls within a character stroke or a binary zero because it does not. This thresholding is a critical step in Optical Character Recognition (OCR). It is also essential for other Character Image Extraction (CIE) applications, such as the processing of machine-printed or handwritten characters from carbon copy forms or bank checks, where smudges and scenic backgrounds, for example, may have to be suppressed. The first algorithm, a nonlinear, adaptive procedure, is implemented with a minimum of hardware and is intended for many CIE applications. The second is a more aggressive approach directed toward specialized, high-volume applications which justify extra complexity.

Exclusive-OR Representations of Boolean Functions *by H. Fleisher, M. Tavel, and J. Yeager, p. 412.* With the goal of making exclusive-OR formulations of switching functions more readily available to designers for implementation in LSI and VLSI technologies, we introduce the concept of an exclusive-OR space in which an exclusive-OR normal form is defined to correspond to the conventional disjunctive normal form. A geometrical representation of exclusive-OR space is described, and its various bases are listed and discussed.

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Periodic Sequences with Optimal Properties for Channel Estimation and Fast Start-Up Equalization *by A. Milewski, p. 426.* The problems of fast channel estimation and fast start-up equalization in synchronous digital communication systems are considered from the viewpoint of the optimization of the training sequence to be transmitted. Various types of periodic sequences having uniform discrete power spectra are studied. Some of them are new and may be generated with data sets commonly used in phase modulation systems. As a consequence of their power spectra being flat, these sequences ensure maximum protection against noise when initial

equalizer settings are computed via channel estimates and noniterative techniques.

An Analysis of the Tolerance to Crosstalk Noise of a Pulse Width Modulation System *by D. I.-H. Park and R. D. Love, p. 432.* This paper reports the results of an investigation to determine the drive degradation caused by random noise in a pulse width modulation (PWM) system originally designed for communicating on coaxial cable but using instead twisted-pair cables. Presented are the analysis of the driver/receiver circuit, the theoretical modeling of the transmitted waveforms over the twisted-pair medium using ASTAP, and a methodology for trading off rms noise for transmission capability. The analysis of the effect of noise on drive distance as a function of allowable error rate is derived, and an example is provided. Finally, a simplified analysis technique is proposed to allow rapid calculation of approximate (yet conservative) results.

A DC-Balanced, Partitioned-Block, 8B/10B Transmission Code *by A. X. Widmer and P. A. Franaszek, p. 440.* This paper describes a byte-oriented binary transmission code and its implementation. This code is particularly well suited for high-speed local area networks and similar data links, where the information format consists of packets, variable in length, from about a dozen up to several hundred 8-bit bytes. The proposed transmission code translates each source byte into a constrained 10-bit binary sequence which has excellent performance parameters near the theoretical limits for 8B/10B codes. The maximum run length is 5 and the maximum digital sum variation is 6. A single error in the encoded bits can, at most, generate an error burst of length 5 in the decoded domain. A very simple implementation of the code has been accomplished by partitioning the coder into 5B/6B and 3B/4B subordinate coders.

Some Methods for Providing OSI Transport in SNA *by P. François and A. Potocki, p. 452.* This paper is made up of three parts: first, a review of open systems interconnection (OSI) objectives, followed by a comparison/contrasting of OSI and systems network architecture (SNA) objectives; second, a description of techniques for providing communication between programs residing in systems based on different architectures; and third, the possible application of these techniques to the four lower OSI layers, demonstrating some ways which could be used to provide connectivity between SNA end users and other heterogeneous system end users through OSI protocols.

Address-Independent Routing for Local Networks *by P. A. Franaszek, p. 464.* A routing methodology is introduced which permits messages to be propagated throughout a network without recourse to destination or origin addresses. Two classes of networks, bidirectional trees and augmented rings, are analyzed from this point of view. An optimality property is proved for the bidirectional tree, and three types of address-independent routing strategies are derived. It is shown that augmented loops, a class of structures incorporating redundant links, may be rerouted to compensate for the failure of any single node or link.

Simulation of Non-Markovian Systems *by D. L. Iglehart and G. S. Shedler, p. 472.* A generalized semi-Markov process provides a stochastic process model for a discrete-event simulation. This representation is particularly useful for non-Markovian systems where it is nontrivial to obtain recurrence properties of the underlying stochastic processes. We develop "geometric trials" arguments which can be used to obtain results on recurrence and regeneration in this setting. Such properties are needed to establish estimation procedures based on regenerative processes. Applications to modeling and simulation of ring and bus networks are discussed.

A Local Communications Network Based on Interconnected Token-Access Rings: A Tutorial *by N. C. Strole, p. 481.* Local area networks are expected to provide the communications base for interconnecting computer equipment and terminals over the next decade. The primary objective of a local area network (LAN) is to provide high-speed data transfer among a group of nodes consisting of data-processing terminals, controllers, or computers within the confines of a building or campus environment. The network should be easily accessible, extremely reliable, and extendible in both function and physical size. The rapid advances in computing and communications technology over the last two decades have led to several different transmission schemes and media types that could be used in these networks. The star/ring wiring topology with token-access control has emerged as a technology that can meet all of these objectives. The requirements of small networks with just a few nodes, as well as those of very large networks with thousands of nodes, can be achieved through this one architecture. This paper is a tutorial of the fundamental aspects of the architecture, physical components, and operation of a token-ring LAN. Particular emphasis is placed on the fault detection and isolation capabilities that are possible, as well as the aspects that allow for network expansion and growth. The role of the LAN relative to IBM's Systems Network Architecture (SNA) is also discussed.

Optimization of Relational Expressions Using A Logical Analogon *by G. A. Blaauw, A. J. W. Duijvestijn, and R. A. M. Hartmann, p. 497.* An expression applying to a relational database is optimized by mapping the expression upon set expressions which, in turn, are transformed into logical expressions. These logical expressions then are optimized, taking into account the constraints that are inherent in relational expressions and the costs of those expressions. Subsequently a reverse transformation to relational expressions is applied. The method is developed for the traditional relational operators and is applicable to a variety of cost criteria. Common subexpressions as well as redundant expressions are optimized. A new relational operation "*split*" is proposed that may be used effectively in an optimized

expression. Results obtained with a model for the optimization method are presented.

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System/370 Extended Architecture: Facilities for Virtual Machines *by P. H. Gum, p. 530.* This paper describes the evolution of facilities for virtual machines on IBM System/370 computers, and presents the elements of a new architectural facility designed for the virtual-machine environment. Assists that have been added to various System/370 models to support the use of virtual machines are summarized, and a general facility for this purpose which was introduced with the System/370 Extended Architecture (370-XA) is described. A new instruction of the 370-XA architecture places the machine in a specific mode in which several special capabilities are enabled. These allow the machine to provide execution in the virtual-machine environment of most of the instructions (including many privileged instructions) and most of the facilities (such as dynamic address translation) of both the System/370 and the 370-XA architectures. The major features of this new facility are individually discussed and summarized.

On Murphy's Yield Formula *by B. Meister, p. 545.* Some properties of yield are presented, and one lower and three upper bounds for yield are derived. Some of these bounds represent yield formulas already known as useful approximations. Pure Poisson statistics for defect density provides the lower bound. The upper bounds are obtained with mixtures of Poisson distributions and a formula of Price and Stapper.

Modeling of Integrated Circuit Defect Sensitivities *by C. H. Stapper, p. 549.* Until now only cursory descriptions of mathematical models for defect sensitivities of integrated circuit chips have been given in the yield literature. This paper treats the fundamentals of the defect models that have been used successfully at IBM for a period of more than fifteen years. The effects of very small defects are discussed first. The case of photolithographic defects, which are of the same dimensions as the integrated circuit device and interconnection patterns, is dealt with in the remainder of the paper. The relationships between these models and test sites are described. Data from measurements of defect sizes are discussed.

SLAN-4: A Language for the Specification and Design of Large Software Systems *by F. Beichter, O. Herzog, and H. Petzsch, p. 558.* The language SLAN-4 has been defined in view of the need for formal tools supporting the specification and design of large software systems. It offers its users language constructs for algebraic and axiomatic specifications as well as for design in pseudocode. One of its major design goals has been to ease subsequent refinements of a (given) specification. The user can start his development with an informal high-level specification which can be formalized and implemented at a later date by using lower-level concepts. This paper provides the formal definitions of the SLAN-4 language, discusses the design decisions, and presents examples for the use of the syntactic constructs.

Replacing Square Roots by Pythagorean Sums *by C. Moler and D. Morrison, p. 577.* An algorithm is presented for computing a "Pythagorean sum" $a \oplus b = \sqrt{a^2 + b^2}$ directly from a and b without computing their squares or taking a square root. No destructive floating point overflows or underflows are possible. The algorithm can be extended to compute the Euclidean norm of a vector. The resulting subroutine is short, portable, robust, and accurate, but not as efficient as some other possibilities. The algorithm is particularly attractive for computers where space and reliability are more important than speed.

A Class of Numerical Methods for the Computation of Pythagorean Sums *by A. A. Dubrulle, p. 582.* Moler and Morrison have described an iterative algorithm for the computation of the Pythagorean sum $(a^2 + b^2)^{1/2}$ of two real numbers a and b. This algorithm is immune to unwarranted floating-point overflows, has a cubic rate of convergence, and is easily transportable. This paper, which shows that the algorithm is essentially Halley's method applied to the computation of square roots, provides a generalization to any order of convergence. Formulas of orders 2 through 9 are illustrated with numerical examples. The generalization keeps the number of floating-point divisions constant and should be particularly useful for computation in high-precision floating-point arithmetic.

Bending and Stretching an Elastic Strip Around a Narrow Cylindrical Drum *by H. C. Lee and H. D. Conway, p. 590.* An analysis is made of the deflected forms assumed by an elastic strip when it is bent and stretched around a rigid drum. A summary is first given of the method of analysis used and the results obtained in a previous study where the drum width is equal to or greater than that of the strip. This work is then extended to the case where the strip width exceeds that of the drum. Deflected forms and contact regions are delineated for a strip-width/drum-width ratio of two and for various values of two parameters: anticlastic deformation and tension.

Automated Twisted-Pair Wire Bonding *by D. E. Houser and K. J. Lubert, p. 598.* A need for highly dense and reworkable external interconnections with controlled characteristic impedance on high-performance printed-circuit boards led to the development of the process and equipment described in this paper. These interconnections are required to implement engineering changes, to install precise circuit delays, to repair printed-circuit defects, and to complete interconnections not possible with printed circuitry alone. As an economical way to meet the characteristic impedance requirement of $80 \pm 10\ \Omega$ and the density requirement for terminations on a 2.5-mm "staggered" grid (twice as dense as a 2.5-mm-square grid), 39-gauge twisted-pair wire is used.

A solder-reflow process bonds the wires to the printed circuitry and meets the need for reworkability. Computer-controlled equipment, developed to install twisted-pair wires at production rates, is now being used in several IBM plants worldwide.

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Optimizing Preventive Service of Software Products *by E. N. Adams, p. 2.* The implementer of a large, complex software system cannot make it completely defect free, so he must normally provide fixes for defects found after the code is put into service. A system user may do preventive service by installing these fixes before the defects cause him problems. Preventive service can benefit both the software developer and the software user to the extent that it reduces the number of operational problems caused by software errors, but it requires the expenditure of the resources required to prepare, disseminate, and install fixes; and it can be the cause of additional software problems caused by design errors introduced into the code by fixes. The benefit from removing a given defect depends on how many problems it would otherwise cause. Benefits may be estimated by modeling problem occurrence as a random process in execution time governed by a distribution of characteristic rates. It is found that most of the benefit to be realized by preventive service comes from removing a relatively small number of high-rate defects that are found early in the service life of the code. For the typical user corrective service would seem preferable to preventive service as a way of dealing with most defects found after code has had some hundreds of months of usage.

Combined Network Complexity Measures *by N. R. Hall and S. Preiser, p. 15.* Most of the considerable work that has been done in the measurement of software complexity during the past several years has addressed complexity measurement of source code or design languages. Here we describe techniques to measure the complexity of large (>100,000 source lines of code) systems during the software architecture phase, before major design decisions have been made. The techniques to measure and reduce complexity are intuitively reasonable, easy to apply, and produce consistent results. Methods developed include (1) an extension of the graph-theoretic measure developed by McCabe to software architecture, as represented by networks of communicating modules, (2) a general technique that allows the complexity associated with allocation of resources (CPU, tape, disk, etc.) to be measured, and (3) a method that combines module complexity and network complexity, so that design trade-offs can be studied to determine whether it is advantageous to have separate modules for service functions, such as mathematical subroutines, data management routines, etc.

Interactive Language Implementation System *by J. F. Sowa, p. 28.* The Interactive Language Implementation System (ILIS) is a tool for implementing language processors. It is fast enough for conventional compilers and general enough for processing natural languages. ILIS is built around a language for writing grammars. Unlike most compiler-compilers, the language includes a full range of semantic operators that reduce or eliminate the need for invoking other programming languages during a translation. ILIS is also highly interactive: It has facilities for tracing a parse and for adding or deleting grammar rules dynamically. This paper describes the features of ILIS and its use in several different projects.

Experience with Access Functions in an Experimental Compiler *by F. N. Ris, p. 40.* This paper describes an access function subsystem embedded in portions of an experimental microcode compiler which was built and used during 1973–6 using the IBM PL/I optimizing compiler under VM/370 and CMS. The use of the access function subsystem in this context was itself an experiment, performed by a group for all of whom PL/I was a new language and VM/370 a new operating system. The implementation of the subsystem was done strictly within the confines of the PL/I language. The basic objectives were ease of use, provision of a focal point for global storage management, extensive run-time validity checking with appropriate diagnostics, and data protection. Beyond satisfying these objectives, the subsystem proved more valuable than anticipated due to positive contributions made to debugging code in the VM/370 interactive development environment.

A New Programming Methodology for Long-Lived Software Systems *by R. Strom and N. Halim, p. 52.* A new software development methodology based on the language NIL is presented. The methodology emphasizes (1) the separation of program development into functional specification and tuning phases, (2) the use of a fully compilable and executable design, (3) an interface definition and verification mechanism. This approach reduces life-cycle costs and improves software quality because (a) errors are detected earlier, and (b) a single functional design can be re-used to produce many implementations.

A Program Development Tool *by C. N. Alberga, A. L. Brown, G. B. Leeman, Jr., M. Mikelsons, and M. N. Wegman, p. 60.* In this paper we describe how we have combined a number of tools (most of which are tailored to a particular programming language) into a single system to aid in the reading, writing, and running of programs. We discuss the efficacy and the structure of two such systems, one of which has been used to build several large application programs. We report some of the experience we have gained in evolving these systems. We first describe the system components which users have found most important; some of the facilities described here are new in the literature. Second, we attempt to show how these tools form a synergistic union, and we illustrate this point with a number of examples. Third, we illustrate the use of various system commands in the development of a simple program. Fourth, we discuss the implementation of the system components and indicate how some of them have been generalized.

Managing Multi-Version Programs with an Editor *by V. Kruskal, p. 74.* When more than one version of a program must be maintained, generally much of the code is repeated unchanged in many versions. Techniques such as "deltas" and

conditional compilation are commonly used to avoid duplicating these common parts. In addition to saving storage, these methods aid the programmer greatly in managing updates to the versions. Unfortunately, these representations of multi-version programs can appear very unlike a program, making them difficult to edit. Described here is a new method of automating much of the bookkeeping involved in dealing with multi-version programs. It entails use of a special editor that enables a multi-version program to be seen and modified in a fashion that is far closer to that normally permitted for a single-version program.

Mapping Uninterpreted Schemes into Entity-Relationship Diagrams: Two Applications to Conceptual Schema Design *by M. A. Casanova and J. E. Amaral de Sa, p. 82.* A method of mapping sets of uninterpreted record or relation schemes into entity-relationship diagrams is described and then applied to two conceptual design problems. First, the method is applied to the design of relational databases. It is shown that the method can be interpreted as a normalization procedure that maps a given relational schema into a new schema that represents an entity-relationship diagram. That is, the original schema has an interpretation in terms of higher-order concepts, which helps in understanding the semantics of the database it describes. The second design problem is related to the conversion of conventional file systems to the database approach. The method is used in this context to obtain a database conceptual schema from the description of the conventional system, which is one of the fundamental steps of the conversion process.

Performance Analysis of Future Shared Storage Systems *by A. Goyal and T. Agerwala, p. 95.* This paper deals with the analysis and design of two important classes of computer systems: BIP (Billion Instructions Per Second) systems consisting of a few very high performance processors and KMIP (K Million Instructions Per Second) systems with hundreds of low speed processors. Each system has large, shared semiconductor memories. Simple analytic models are developed for estimating the performance of such systems. The models are validated using simulation. They can be utilized to quickly reduce the design space and study various trade-offs. The models are applied to BIP and KMIP systems and their use is illustrated using examples.

***IBM Journal of Research and Development*: Information for Authors** *by H. Freitag, p. 119.* This paper combines background information about the *IBM Journal of Research and Development* with guidelines for the preparation of *Journal* manuscripts. The purpose is to acquaint authors with the *Journal* as a primary, professional publication and to present suggestions to ease the work of author and editor in preparing clear, concise, and useful manuscripts.

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Error-Correcting Codes for Semiconductor Memory Applications: A State-of-the-Art Review *by C. L. Chen and M. Y. Hsiao, p. 124.* This paper presents a state-of-the-art review of error-correcting codes for computer semiconductor memory applications. The construction of four classes of error-correcting codes appropriate for semiconductor memory designs is described, and for each class of codes the number of check bits required for commonly used data lengths is provided. The implementation aspects of error correction and error detection are also discussed, and certain algorithms useful in extending the error-correcting capability for the correction of soft errors such as α-particle-induced errors are examined in some detail.

An Introduction to Arithmetic Coding *by G. G. Langdon, Jr., p. 135.* Arithmetic coding is a data compression technique that encodes data (the data string) by creating a code string which represents a fractional value on the number line between 0 and 1. The coding algorithm is symbolwise recursive; i.e., it operates upon and encodes (decodes) one data symbol per iteration or recursion. On each recursion, the algorithm successively partitions an interval of the number line between 0 and 1, and retains one of the partitions as the new interval. Thus, the algorithm successively deals with smaller intervals, and the code string, viewed as a magnitude, lies in each of the nested intervals. The data string is recovered by using magnitude comparisons on the code string to recreate how the encoder must have successively partitioned and retained each nested subinterval. Arithmetic coding differs considerably from the more familiar compression coding techniques, such as prefix (Huffman) codes. Also, it should not be confused with error control coding, whose object is to detect and correct errors in computer operations. This paper presents the key notions of arithmetic compression coding by means of simple examples.

A Universal Reed-Solomon Decoder *by R. E. Blahut, p. 150.* Two architectures for universal Reed-Solomon decoders are given. These decoders, called time-domain decoders, work directly on the raw data word as received without the usual syndrome calculation or power-sum-symmetric functions. Up to the limitations of the working registers, the decoders can decode any Reed-Solomon codeword or BCH codeword in the presence of both errors and erasures. Provision is also made for decoding extended codes and shortened codes.

Implementation and Evaluation of a (b,k)-Adjacent Error-Correcting/Detecting Scheme for Supercomputer Systems *by J. Arlat and W. C. Carter, p. 159.* This paper describes a coding scheme developed for a specific supercomputer architecture and structure. The code considered is a shortened (b,k)-adjacent single-error-correcting

double-error probabilistic-detecting code with $b = 5$, $k = 1$, and code group width = 4. An evaluation of the probabilistic double-error-detection capability of the code was performed for different organizations of the coding/decoding strategies for the codewords. This led to the selection of a system organization encompassing the traditional feature of memory data error protection and also providing for the detection of major addressing errors that may result from faults affecting the interconnection network communication modules. The cost of implementation is a limited amount of extra hardware and a negligible degradation in the double-error-detection properties of the code.

Fault Alignment Exclusion for Memory Using Address Permutation *by D. C. Bossen, C. L. Chen, and M. Y. Hsiao, p. 170.* A significant improvement in memory fault tolerance, beyond what is already provided by the use of an appropriate error-correcting code (ECC), can be achieved by electronic chip swapping, without any compromise of data integrity as large numbers of faults are allowed to accumulate. Since most large and medium-sized semiconductor memories are organized so that each bit position of the system word (ECC codeword) is fed from a different chip, and quite often from a different array card, or at least from distinct partitions of an array card, the various bit positions have separate address circuitry on the array cards. This fact is important, and can be exploited to provide effective address permutation capability, which allows the realignment of faults which would otherwise have caused an uncorrectable multiple error in an ECC codeword. When faults occur in a codeword to produce an uncorrectable error (UE), the addressing within one of the error bit position array cards can be altered using simple EX-OR circuitry and storage latches. The content of the latches is computed using a fault map of the memory together with an algorithm. These techniques are referred to as Fault Alignment Exclusion (FAE) using address permutation. Practical considerations as to the complexity of the fault map, the number of storage latches per bit position, and the overall effectiveness of the permutation to disperse the expected numbers of errors are presented in this paper.

Fault-Tolerant Design Techniques for Semiconductor Memory Applications *by F. J. Aichelmann, Jr., p. 177.* Advances in semiconductor memory technology towards higher-density and higher-performance memory chips have created new reliability challenges for the memory system designer. An example would be the multiple-bit-per-chip organization with the chip outputs used in the same word. This design structure would be prone to uncorrectable errors with conventionally implemented single-error-correcting double-error-detecting codes. With these newer chips, memory system designers will have to give special attention not only to the types of failures but to ways of minimizing the system impact of reliability defects. In this paper, a number of design approaches are presented for minimizing the effects of chip failures through the use of organizational techniques and through enhancements to conventional error checking and correction facilities. The fault-tolerant design techniques described are compatible with most existing memory designs. An evaluative comparison of these techniques is included, and their application and utility are discussed.

Fault-Tolerant Memory Simulator *by C. L. Chen and R. A. Rutledge, p. 184.* Memory systems in modern computers employ a variety of methods to achieve fault tolerance, such as single- or double-error correction, page deallocation, or the use of spare chips or cells. Such methods ensure that the failure rate of the system is considerably less than the sum of the failure rates of the components. However, these methods also complicate the task of evaluating system reliability. The memory reliability function is too intractable to handle analytically, and we must turn to Monte Carlo methods. This paper describes the Fault-Tolerant Memory Simulator (FTMS), an interactive APL program which uses Monte Carlo simulation to evaluate the reliability of fault-tolerant memory systems.

A General-Purpose Memory Reliability Simulator *by M. R. Libson and H. E. Harvey, p. 196.* With rapid advances in computer memory capacity and performance, coupled with corresponding increases in the expense of field service calls, memory reliability and optimal maintenance strategies have become more and more important in terms of customer satisfaction and field service cost. At the same time, significant improvements in error correction and recovery over recent years have made the prediction of uncorrectable error and field service frequency much more difficult. This paper describes a Monte Carlo simulator which can predict uncorrectable error rates and field-replaceable-unit replacement rates for a wide range of memory architectures and under a variety of maintenance strategies. The model provides valuable information for performing sensitivity studies of intrinsic failure rates for memory components, for performing tradeoff studies of alternative storage module and card organizations, for evaluating system functions, and for establishing optimum maintenance strategies.

Analysis of Correctable Errors in the IBM 3380 Disk File *by T. D. Howell, p. 206.* A method of analyzing the correctable errors in disk files is presented. It allows one to infer the most probable error in the encoded-data stream given only the unencoded readback and error-correction information. This method is applied to the errors observed in seven months of operation of four IBM 3380 head-disk assemblies. It is shown that nearly all the observed errors can be explained as single-bit errors at the input to the channel decoder. About 90 percent of the errors were related to imperfections in the disk surfaces. The remaining 10 percent were mostly due to heads which were unusually susceptible to random noise-induced errors.

Iterative Exhaustive Pattern Generation for Logic Testing *by D. T. Tang and C. L. Chen, p. 212.* Exhaustive pattern logic testing schemes provide all possible input patterns with

respect to an output in the set of test patterns. This paper is concerned with the problem that arises when this is to be done simultaneously with respect to a number of outputs, using a single test set. More specifically, in this paper we describe an iterative procedure for generating a test set consisting of n-dimensional vectors which exhaustively covers all k-subspaces simultaneously, i.e., the projections of n-dimensional vectors in the test set onto any input subset of a specified size k contain all possible patterns of k-tuples. For any given k, we first find an appropriate N ($N>k$) and generate an efficient N-dimensional test set for exhaustive coverage of all k-subspaces. We next develop a constructive procedure to expand the corresponding test matrix (formed by taking test vectors as its rows) such that a test set of N^2-dimensional vectors exhaustively covering the same k-subspaces is obtained. This procedure may be repeated to cover arbitrarily large n ($n = N^{2^i}$ after i iterations), while keeping the same k. It is shown that the size of the test set obtained this way grows in size which becomes proportional to (log n) raised to the power of [log $(q+1)$], where q is a function of k only, and is approximated (bounded closely below) by $k^2/4$ in binary cases. This approach applies to nonbinary cases as well except that the value of q in an r-ary case is approximated by a number lying between $k^2/4$ and $k^2/2$.

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Preface *by E. E. Lucente, p. 233.*

Introduction to Topical Issue on Non-Impact Printing Technologies *by R. A. Myers and J. C. Tamulis, p. 234.* In this paper, we present an overview of the technologies of importance in computer output printing, providing a background for the succeeding papers in this issue. IBM workers have played a key role in the evolution of computer printers from a few marginally reliable complex mechanisms to an industry which today counts annual sales of over ten billion dollars worldwide. Thus, in this necessarily brief description of the different technologies we mention those in which the IBM role was particularly noteworthy, with specific mention of machines which brought the technologies to the marketplace.

Technology Trends in Electrophotography *by M. H. Lee, J. E. Ayala, B. D. Grant, W. Imaino, A. Jaffe, M. R. Latta, and S. L. Rice, p. 241.* Selected innovations and advances in electrophotographic printing are reviewed. Technological advances in photoreceptors, imaging techniques, toner development and cleaning, fusing, sensors, and new machine configurations and functions are discussed with respect to their possible applicability to future electrophotographic imaging systems. In general, improvements in print quality and reliability remain the main goals. In specific applications, added functions and an increased range of usable media are highly desired.

Introduction to the IBM 3800 Printing Subsystem Models 3 and 8 *by R. C. Miller, Jr., p. 252.* The IBM 3800 Printing Subsystem Models 3 and 8 are high-speed, non-impact, electrophotographic printers which are designed for system printing, text, and graphics applications requiring flexibility and high print quality. Features such as their print density of 240×240 pels/in.^{2} and all-point addressability extend substantially their printing capabilities beyond those of the Models 1 and 2.

Technology of the IBM 3800 Printing Subsystem Model 3 *by D. McMurtry, M. Tinghitella, and R. Svendsen, p. 257.* IBM has introduced the 3800 Model 3 electrophotographic printer, which is a modified version of the previously developed Model 1. The Model 3 improves the print density of the 3800 Model 1 from 180×144 pels/in.^{2} to 240×240 pels/in.^{2} and permits each pel to be addressed individually. The laser print head was modified to create the higher density by using the same laser, focusing to a smaller spot size, slowing down the speed of the rotating mirror, and developing a dual-beam system. Beam-power balance and beam separation were selected for optimum print quality. The dual-beam print head required the development of a new photoconductor with improved sensitivity. That photoconductor also displayed a significantly increased lifetime. Improved manufacturing techniques were developed to reduce photoconductor defects. A digital voltmeter and a new processor were introduced that reduced the cost of the process servos by eliminating previously hard-wired elements.

Electrophotographic Printer Control as Embodied in the IBM 3800 Printing Subsystem Models 3 and 8 *by C. Barrera and A. V. Strietzel, p. 263.* Control of the IBM 3800 Models 3 and 8 electrophotographic printers is achieved by use of a fundamentally different control system than was used in their predecessors, the Models 1 and 2. As a result, printing of composed pages or electronic overlays can include text of many different font sizes and styles printed in multiple orientations, as well as raster images up to a full page in size. The printers manage stored resources, including fonts, segments of pages, and electronic overlays. Pages are composed inside the printers in a logical sequence, instead of by the more traditional line-by-line sequence. This, as well as the capability to position text and images at any addressable point, enhances usability. A high-speed, table-driven character generator, a new command set, and a microcoded control unit make all of this possible.

Print Quality Measurements for High-Speed Electrophotographic Printers *by J. L. Crawford, C. D. Elzinga, and R. Yudico, p. 276.* Described here are some of the characteristics that make electrophotographic printing esthetically pleasing, and the use of a recently developed computer-controlled scanner for measuring those characteristics. New print quality measurements are described (for example, measurements of modulation, image gray-scale fidelity, and tangential-edge roughness) that allow the

monitoring of the advanced printing functions made possible by all-point addressability. The requirements for and implementation of the scanner are discussed. Also discussed are the effects and limitations on print quality measurement resolution imposed by the algorithms used and the scanner; the effect of light scatter by the paper; and the usefulness of the print quality measurements as an aid in making design trade-off decisions and in manufacturing control.

Paper Material Considerations for System Printers *by J. Borch and R. G. Svendsen, p. 285.* Laser printing of continuous forms by means of electrophotographic imaging requires that the paper on which the printing is carried out show good handling characteristics at fast machine speeds and be compatible with toner transfer and fixing. Toner transfer requires suitable electrical paper characteristics, similar to those of xerographic cut sheets intended for use in electrophotographic cut-sheet copiers and printers. Hot-pressure fusing in the IBM 3800 printing subsystem has been shown to require adequate paper-fiber wettability by the hot molten toner. Therefore, characteristics of paper chemistry, and in particular paper sizing, are essential in creating good image fixing (fusing). In addition, the temperature and pressure in the fusing assembly affect the thermal and dimensional stability of the paper. For the 3800, this necessitated modifications in roll design within the fusing station in order to ensure satisfactory paper handling.

Flash Fusing in Electrophotographic Machines *by G. W. Baumann, p. 292.* A theoretical model of the flash fusing process for electrophotographic machines was developed using the joint solution of a nonlinear circuit equation and the one-dimensional thermal diffusion equation. Numerous experiments were run using different toners according to the size of toner particles and the pulse width in order to determine the minimum energy that was required for fusing. The experiments confirm that this model predicts reasonably well what was observed in the lab. The melt depth required for good fusing is slightly less than mean particle size. At that depth the temperature is somewhat greater than the temperature required in the nip of a hot roll fuser for the same toner. Under typical flash fusing, the top surface of the toner is subjected to considerably higher temperatures than the melt temperature of the toner. From the combined analytical and experimental results, the proper compromises can be made for efficiency and volatiles.

Multiple-Nozzle Ink Jet Printing Experiment *by R. H. Darling, C.-H. Lee, and L. Kuhn, p. 300.* An experimental printer is described which utilizes a densely packed array of ink jets operated in a binary, pressurized, asynchronous mode. The printer configuration, the ink jet head structure, the operating point, and the maintenance approach are all discussed.

The Application of Drop-on-Demand Ink Jet Technology to Color Printing *by F. C. Lee, R. N. Mills, and F. E. Talke, p. 307.* The application of drop-on-demand ink jet technology to high-frequency and high-resolution color printing is investigated using an experimental multi-nozzle print head. Cross talk and drop misregistration are examined as a function of drop ejection frequency. Typical print samples from scanned and computer-generated data are obtained and the dependence of print quality on various parameters such as drop ejection frequency, ink composition, and paper quality is discussed.

Experimental and Theoretical Study of Wave Propagation Phenomena in Drop-on-Demand Ink Jet Devices *by D. B. Bogy and F. E. Talke, p. 314.* This paper presents experimental observations and a theoretical analysis of the operation of drop-on-demand piezoelectric ink jet devices. By studying experimentally the dependence of several operating characteristics on the length of the cavity in the nozzle of an ink jet device, we have gained insight into the physical phenomena underlying the operation of such a device. It is concluded that drop-on-demand ink jet phenomena are related to the propagation and reflection of acoustic waves within the ink jet cavity. A simple analysis is carried out on the basis of linear acoustics which is in good agreement with the experimental observations.

Numerical Calculation of the Fluid Dynamics of Drop-on-Demand Jets *by J. E. Fromm, p. 322.* A numerical method that makes use of the complete incompressible flow equations with a free surface is discussed and used to study an impulsively driven laminar jet. Flow behavior dependence upon fluid properties (characterized by a Reynolds number over Weber number nondimensionalization) is compared for drop integrity purposes. Several variations of square wave pressure history applied at a nozzle inlet are discussed in relation to drop velocities produced and structure of ejected drops. Timewise development of flow both interior and exterior to the nozzle is illustrated through computed contour sequences.

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Statistical failure analysis of system timing *by D. R. Tryon, F. M. Armstrong, and M. R. Reiter, p. 340.* Techniques are developed that quantify the probability that large computer systems will meet their cycle time objectives. Both approximation techniques and rigorous multivariate statistical techniques are described. A method is developed that enumerates the cycle-limiting paths so that these approaches can be utilized. The results of these techniques enable system designers to ensure that performance and reliability objectives are met.

Measures of ideal execution architectures *by M. J. Flynn and L. W. Hoevel, p. 356.* This paper is a study in ideal computer architectures or program representations. We define measures of "ideal" architectures that are related to the higher-level representation used to describe a program at the

source language level. Traditional machine architectures name operations and objects which are presumed to be present in the host machine: a memory space of certain size, ALU operations, etc. An ideal language-based architecture is based on a specific higher-level (source) language, and uses the operations in that language to describe transformations over objects in that language. The notion of ideal is necessarily constrained. The object program representation must be easily decompilable (i.e., the source is readily reconstructable). It is assumed that the source itself is a good representation for the original problem; thus any nonassignment operation present in the source program statement appears as a single instruction (operation) in the ideal representation. All named objects are defined with respect to the scope of definition of the source program. For simplicity of discussion, statistical behavior of the program and language is assumed to be unknown; Huffman codes are not used. From the above, canonic interpretive (CI) measures are developed. CI measures apply to both the space needed to represent a program and the time needed to interpret it. Example-based CI measures are evaluated for a variety of contemporary architectures, both host-and language-oriented, as well as a CI-derived language-oriented architecture.

Design considerations of a static LSSD polarity hold latch pair *by A. Correale, p. 370.* There are many considerations relating to the design of a static LSSD polarity hold latch pair. High performance, low power dissipation, small size, and stability are some of the major requirements for a good design. The engineering trade-offs needed to ensure that all goals are met are discussed.

All points addressable raster display memory *by R. Matick, D. T. Ling, S. Gupta, and F. Dill, p. 379.* This paper discusses display designs which store the image point by point in random access memory, so that independent update of every pixel is possible. A frequent bottleneck in the design of high performance displays of this type is the available bandwidth of the memory subsystem. In this paper, we focus on this issue and present features of a customized dynamic RAM chip which can readily provide the necessary bandwidth and thus greatly simplify the design of very high performance APA raster scan displays. The customized RAM chip is quasi-two-ported. After briefly introducing APA raster displays, we discuss display memory system design and the design of the proposed custom memory chip. We describe the second port for the video refresh, which makes the primary port available for update almost continuously. We also discuss modifications to the existing primary port to make it easily usable for the parallel update required for high update performance as well as for other applications.

A mapping and memory chip hardware which provides symmetric reading/writing of horizontal and vertical lines *by D. L. Ostapko, p. 393.* This paper describes a mapping and memory chip hardware for enhancing the performance of an APA display. The approach describes a modification to the primary port of a quasi-two-ported memory. This modification allows several contiguous horizontal or vertical bits to be read or written in one cycle. The number of bits that can be stored is given by the number of memory chips. The hardware modifications can be on or off chip, and if on chip, the chip can still be used as a conventional memory chip. Simple modifications to the hardware will support different screen sizes.

Reduction of random noise from multiband image data using phase relationships among their Fourier coefficients *by J. V. Dave and J. Gazdag, p. 399.* The problem of reducing the random noise from multiband image data is examined, taking a nine-band image data set of a terrestrial scene and adding a significant amount of noise to the original pixel value of each band. For each of these data sets, data of three nearby bands generally exhibit a high correlation among them. Selected data for several sets of three nearby bands are transformed from the spatial domain to the frequency domain to study phase relationships (i.e., coherency) among their Fourier coefficients of various frequencies. It is shown that, in general, the addition of random noise results in the rapid change, with frequency, of a quantity called the coherency measure. (This is a quantitative measure of the phase agreement among the phases of various Fourier coefficients at a given frequency.) The coherency measure vs. frequency curve for a given data line is then used to attenuate various Fourier coefficients of the corresponding nearby bands of that line. It is then shown that the inverse transformation of such modified Fourier coefficients results in a statistically significant reduction of noise from the data of single lines, or from those data of some finite areas of the image. Results of a supervised boxcar multispectral classification with the original as well as various modified data sets of the selected image are also presented to provide additional guidance in the use of such a sophisticated analytic procedure in image processing.

Empty arrays in extended APL *by D. L. Orth, p. 412.* During the past several years considerable work has been done on extending APL in three areas: operators, heterogeneous data, and nested data. In each area a proposed extension must treat empty arrays consistently. In this paper various possibilities for providing consistent behavior are presented. The new proposals possess at least one of two important qualities in which older proposals tend to be deficient: consistent behavior is independent of the structural properties of rank and nesting, and the user has control over the behavior when he wants it.

Software reliability analysis models *by M. Ohba, p. 428.* This paper discusses improvements to conventional software reliability analysis models by making the assumptions on which they are based more realistic. In an actual project environment, sometimes no more information is available than reliability data obtained from a test report. The models described here are designed to resolve the problems caused

by this constraint on the availability of reliability data. By utilizing the technical knowledge about a program, a test, and test data, we can select an appropriate software reliability analysis model for accurate quality assessment. The delayed S-shaped growth model, the inflection S-shaped model, and the hyperexponential model are proposed.

The digital data exchange—A space-division switching system *by E. Hopner and M. A. Patten, p. 444.* The user requirements for an automated switch for computer terminals in a large establishment or laboratory environment are discussed. This is followed by an explanation of the design requirements, and finally by a description of the significant features of the digital data exchange (DDEX), a microprocessor-controlled user-transparent space-division digital data switch of modular design which is capable of connecting 512 to 2048 lines from various types of IBM terminals to different control units, thereby substantially saving interconnection resources.

Resist profile control in E-beam lithography *by S. J. Gillespie, p. 454.* Imaging studies have confirmed that a desired resist profile can be obtained by selecting the appropriate combination of process parameters: dose, interrupted development, pattern bias, and resist thickness. Bias sensitivity of the resist image to process parameters was measured using a positive diazo resist with nonlinear development characteristics on an IBM EL-3 E-beam tool. Because of superior bias stability, top-edge imaging with undercut profiles in a single-layer resist was found to provide many of the imaging advantages of a multilayer system. Sufficient resolution and image quality are obtained to extend the application of a single-layer resist system to 1-μm lithography.

Modeling of defects in integrated circuit photolithographic patterns *by C. H. Stapper, p. 461.* In a previous paper by the same author the foundation was laid for the theory of photolithographic defects in integrated circuits. This paper expands on the earlier one and shows how to calculate the critical areas and probability of failure for dense arrays of wiring. The results are used to determine the nature of the defect size distribution with electronic defect monitors. Several statistical techniques for doing this are described and examples are given.

Aspects of the traveling salesman problem *by M. Held, A. J. Hoffman, E. L. Johnson, and P. Wolfe, p. 476.* For fifty years the traveling salesman problem has fascinated mathematicians, computer scientists, and laymen. It is easily stated, but hard to solve; it has become the prototypical hard problem in theoretical computer science. A large part of the extensive research conducted by IBM in the broad area of optimization, or mathematical programming, contributed to or was inspired by aspects of this challenging problem. This article reviews some of that work as well as recent developments in techniques that were used on the largest traveling salesman problem ever solved.

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A software architecture for a mature design automation system *by R. L. Taylor, p. 501.* Design automation systems are groups of programs used to aid the design of the electronic portions of computers. IBM has used such systems for over twenty-five years, and has a large number of experienced users who place severe requirements upon their design automation system. The essential requirement is that design programs must be easy to use in the way that a particular development location wishes to use them. Design programs which cannot be changed to meet local requirements are not acceptable. The software structure portion of an architecture for a design automation system which meets these requirements is described; interactive and foreground design applications are stressed. The structure involves a uniform set of services, such as command languages and terminal access methods, needed to support the design application, and a formal, two-part partitioning of the design application itself. Modularity and good interfaces are important parts of the software structure which permit a development laboratory to change the application enough for it to be easily used. These changes are the rule, not the exception. Examples of such changes are given, based upon early user experience. The applicability of this architecture to future system needs such as distributed data and distributed processing is discussed.

A device-independent graphics package for CAD applications *by R. B. Capelli and G. C. Sax, p. 512.* GSSP (Graphics Support Subroutine Package) is a device-independent two-dimensional graphics package developed by Engineering Design Systems (EDS) to support several major electronic and mechanical computer-aided design applications within IBM. Graphics systems supported range from interactive, high-function, distributed-graphics workstations to passive graphic-output devices. GSSP provides many of the functions usually found in other device-independent graphics packages, with additional support for hierarchically structured display files and distributed graphics systems. The major functions provided by GSSP are described, and an overview of the implementation is presented to show how issues such as interactive performance and human factors are addressed.

An interactive system for VLSI chip physical design *by W. H. Elder, P. P. Zenewicz, and R. R. Alvarodiaz, p. 524.* The Federal Systems Division has developed a structured design methodology and a companion chip physical design system that has been used to build seven large VLSI chips (ranging in size from 7K to 36K logic primitives). Using the MVISA system, a logic designer has complete control and responsibility for the total chip design. Our experience has been that when this highly interactive software and methodology is used, chip physical design requires less than

two weeks. This is a significant savings in design time; but more importantly the designer can allocate more schedule for logic design and simulation. This paper describes how FSD's unique interactive physical design system has improved productivity of VLSI design.

LSS: A system for production logic synthesis *by J. A. Darringer, D. Brand, J. V. Gerbi, W. H. Joyner, Jr., and L. Trevillyan, p. 537.* For some time we have been exploring methods of transforming functional specifications into hardware implementations that are suitable for production. The complexity of this task and the potential value have continued to grow with the increasing complexity of processor design and the mounting pressure to shorten machine design times. This paper describes the evolution of the Logic Synthesis System from an experimental tool to a production system for the synthesis of masterslice chip implementations. The system was used by one project in IBM Poughkeepsie to produce 90 percent of its more than one hundred chip parts. The primary reasons for this success are the use of local transformations to simplify logic representations at several levels of abstraction, and a highly cooperative effort between logic designers and synthesis system designers to understand the logic design process practiced in Poughkeepsie and to incorporate this knowledge into the synthesis system.

Automated technology mapping *by J. L. Gilkinson, S. D. Lewis, B. B. Winter, and A. Hekmatpour, p. 546.* Logic "mapping," or "transformation," refers to the process of converting a logic design from one form of specification to another. The output is usually a specific technology implementation and the input could range from a previous technology implementation to a high-level design language. Motivated initially by the problem of test case generation for new technologies, a logic transformation system, known as the Technology Mapping System (TMS), was developed. This system has focused on the problem of technology-to-technology mapping involving gate array or standard cell logic families. TMS makes use of an intermediate notation, called GLN, and uses several forms of "rules" to control the mapping process. This paper discusses the history and general operation of TMS, and makes a comparison of transformations from different types of sources.

Hardware design and description languages in IBM *by L. I. Maissel and H. Ofek, p. 557.* Hardware design languages (HDLs) allow computer hardware to be described in sufficient detail to be simulated and built, such a description being at a sufficiently high level of abstraction to make the complete design readily intelligible to anyone skilled in that language. A number of HDLs have been developed and are in use in IBM. To date, no overwhelming case can be made for choosing any one HDL over the others. The major trends in HDL are discussed. Several examples of HDLs are presented in some detail. VHDL, the yet-to-be released HDL which is to serve as a front end to the U.S. Government's Very High Speed Integrated Circuits program, is among these.

Using a hardware simulation engine for custom MOS structured designs *by Z. Barzilai, D. K. Beece, L. M. Huisman, and G. M. Silberman, p. 564.* Mixed-level simulation techniques are widely used in VLSI designs for verification and test evaluation. In this paper we indicate how to perform mixed-level simulation on structured MOS designs using the Yorktown Simulation Engine (YSE), a hardware simulator developed at IBM. On the YSE, simulation can be done at the functional, gate, and transistor levels. The design specification used by the YSE is well suited for mixed-level simulation, particularly with regard to interfacing the different levels. We apply our techniques to an nMOS design to show the important features of our approach.

PSI: A symbolic layout system *by R.-D. Fiebrich, Y.-Z. Liao, G. Koppelman, and E. Adams, p. 572.* A symbolic layout tool, PSI, is described for use with IBM circuit technology. Significant features of PSI are used with multiple circuit technologies, adaptation to rapid changes of technology design rules, creation of nested designs, and extensive designer control over the spacing process.

Constraint solver for generalized IC layout *by P. W. Cook, p. 581.* This paper presents a constraint solver suitable for use in a general symbolic IC layout system. The essential features of the constraint solver, which is intended to place few restrictions on the source of the constraints to be solved, are that it accommodate mixed equality and inequality constraints, that it allow selective "maximization" of variables, that it proceed with any number of variables given user-defined values, and that it fail to produce a solution only when no solution exists. These features all flow from the desire to provide a constraint solver suitable for use in an "open" system, in which there are no restrictions on the form or order of the constraints. The algorithm presented meets these objectives while remaining reasonable in its use of storage and time. An extension to the class of constraints acceptable by the constraint solver is presented; the extension of the system to this added constraint class has yet to be done.

Custom Chip/Card Design System *by A. M. Barone and J. K. Morrell, p. 590.* The Custom Chip/Card Design System (CCDS) is a set of software applications, tied together via a common data interchange, that is used for the design, analysis, and checking of custom electronic circuits. CCDS is intended to unite the separate electrical, logical, and physical design phases into a single design process. The underlying principle of the system rests on the idea of describing the product as a generalized network, with multiple overlapping views that correspond to the different design phases. In addition to the applications contained within CCDS, there are also links to other software tools for such things as circuit simulation.

ACORN: A system for CVS macro design by tree placement and tree customization *by P. S. Hauge and E. J. Yoffa, p. 596.* ACORN is a system for the physical design of

cascode voltage switch (CVS) macros which utilizes tree placement and tree customization to improve macro wirability. The results obtained by designing a 43-tree differential (DCVS) macro on a masterslice chip image are presented to illustrate the design improvements. In this example, tree placement reduces wire length and via count by 12 percent relative to a transistor-pair placement design. Tree customization increases this improvement to 25 percent, and increases the porosity of the wired macro to vertical global wires from 8 percent for tree placement alone to 15 percent.

KWIRE: A multiple-technology, user-reconfigurable wiring tool for VLSI *by P. C. Elmendorf, p. 603.* In a VLSI design environment where a range of chip technologies are available and concurrent chip designs are commonplace, it is not feasible to build a wiring program for each technology. Additionally, a chip's design methodology may demand specific abilities from a wiring program. KWIRE was developed to meet the needs of a multiple-technology, multiple-methodology VLSI design community. It has been used on a range of chips, from small designs to custom microprocessors. Modeling the users' designs and design rules in geometric terms allows KWIRE to handle such a diversity of chip designs. This paper describes the KWIRE system and router.

An iterative-improvement penalty-function-driven wire routing system *by R. Linsker, p. 613.* A wire routing system (VIKING) has been developed for interconnection packages. It uses iterative-improvement methods that allow "illegalities" (such as wire crossings within a plane) at intermediate stages of the routing, eliminates some drawbacks of conventional sequential routers, and extends the range of penalty functions with respect to which a wiring configuration can be optimized. Efficient routing in directionally uncommitted planes is provided; specification of preferred-direction (x and y) planes is optional but not required. Significant reductions in required manual embedding effort, number of vias required, routed wire length, and the number of signal planes required to wire a package, have been found, compared with sequential routers that have been used. Improved automatic control of electrical crosstalk noise has also been provided. In addition to presenting VIKING methods and results, we discuss other issues relating to wiring methods and global optimization. Application of these methods to chip design is also discussed.

A CMOS LSSD test generation system *by D. Leet, P. Shearon, and R. France, p. 625.* Automatic test pattern generators based on the stuck-fault concept are theoretically inadequate in their ability to generate test patterns for CMOS circuits. A new set of pin faults, called CMOS faults, is discussed that can represent the necessary test pattern sequences for these circuits. Processing of these faults by a new test pattern generator, called the Enhanced Test Generator (ETG), is also described.

Yield model for fault clusters within integrated circuits *by C. H. Stapper, p. 636.* Generalized negative binomial statistics turns out to be a model of the fault distribution in very large chips or wafers with internal defect clusters. This is expected to influence large chip and full wafer redundancy requirements. Furthermore, the yield appears to be affected by an experimental dependence of the average number of faults on chip area.

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Preface: Advances in materials and processes for printed circuit packaging technology *by D. P. Seraphim, P. A. Toole, W. T. Chen, and R. Rosenberg, p. 652.*

Moisture solubility and diffusion in epoxy and epoxy-glass composites *by L. L. Marsh, R. Lasky, D. P. Seraphim, and G. S. Springer, p. 655.* The solubility and kinetics of moisture transport mechanisms in epoxy-type resin and resin-glass composites have been investigated over a range of partial pressure and temperature. Moisture absorption-desorption in these systems is a quasi-reversible process, the kinetics of which are non-Fickian (Type II) and dependent on prior history. The multistaged sorption and transport behavior are interpreted in terms of multiphase models.

Bending-cantilever method for the study of moisture swelling in polymers *by B. S. Berry and W. C. Pritchet, p. 662.* Self-induced bending of a bilayer strip is shown to be a simple but sensitive method for the study of water absorption and swelling in polymers. Expressions for both the time-dependent and equilibrium curvature of the strip have been derived, enabling both diffusional and dilatational parameters to be extracted from experimental data. To illustrate the technique, it is shown that a vacuum-dried epoxy swells linearly with water content, at a rate of 0.93% in volume per weight percent of water. Desorption into vacuum has been observed under diffusion-controlled conditions and the diffusion coefficient for water in the epoxy found to be 2.5×10^{-9} cm^2/s at 295K.

Mechanisms of electroless metal plating: I. Mixed potential theory and the interdependence of partial reactions *by P. Bindra, D. Light, and D. Rath, p. 668.* Electroless plating reactions are classified according to four overall reaction schemes in which each partial reaction is either under diffusion control or electrochemical control. The theory of a technique, based on the observation of the mixed potential as a function of agitation, concentration of the reducing agent, and concentration of metal ions, is presented. By using this technique it is shown that in electroless copper plating the copper deposition reaction is diffusion-controlled, while the formaldehyde decomposition reaction is activation-controlled. Values of the kinetic and mechanistic parameters for the partial reactions obtained by this method and by other electrochemical methods indicate that the two partial reactions are not independent of each other.

Mechanisms of electroless metal plating: II. Decomposition of formaldehyde *by P. Bindra, J. M. Roldan, and G. V. Arbach, p. 679.* A detailed investigation of the decomposition of formaldehyde was carried out to account for the fact that formaldehyde decomposition on Group VIII metals, e.g., Pd, occurs without simultaneous hydrogen generation, while on Group IB metals, e.g., Cu, formaldehyde decomposition is accompanied by hydrogen evolution. It was found that in principle metals may be divided into three main classes: (a) metals with positive free energy of hydrogen adsorption, (b) metals with free energy of hydrogen adsorption close to zero, and (c) metals with negative free energy of hydrogen adsorption. In the case of class (a) metals formaldehyde oxidation is accompanied by hydrogen evolution; for class (b) metals there is no simultaneous hydrogen evolution; and class (c) metals show low catalytic activity for formaldehyde oxidation. Hence, formaldehyde cannot be used as a reducing agent for electroless plating of class (c) metals.

Initiation of electroless Cu plating on nonmetallic surfaces *by J. Horkans, C. Sambucetti, and V. Markovich, p. 690.* Electroless plating of a metal on a dielectric substrate requires the prior deposition of a catalyst such as a Pd-Sn colloid consisting of a metallic Pd core surrounded by a stabilizing layer of Sn ions. The activation step (deposition of the colloid) is usually followed by an acceleration step (removal of excess ionic tin). Adhesion of the deposit to the substrate is improved by mechanical and chemical pretreatment steps. An electrochemical method has been developed for assessing the catalytic activity of Pd-Sn colloids. Hydrogen sorption in the Pd in the colloid can be correlated with catalytic activity, since Pd accessible for the H-sorption reaction is also accessible as the catalyst for the electroless deposition reaction. These conclusions have been confirmed by surface analytical techniques and by functional tests. The efficacy of various accelerating solutions has also been assessed.

Microstructure evolution during electroless copper deposition *by J. Kim, S. H. Wen, D. Y. Jung, and R. W. Johnson, p. 697.* A study using transmission and scanning electron microscopy was made of the evolution of the microstructure of electroless plated Cu on activated amorphous substrates and on single-crystal Cu grains. On amorphous substrates activated in a $PdCl_2$–$SnCl_2$ colloidal solution, Sn atoms dissolved into the plating solution concurrently with Cu deposition on the substrate during the initial stage of deposition. The very small face-centered-cubic grains of Cu-Pd solid solution agglomerated into much larger particles and later coalesced into spherical grains. As the grains grew, they developed crystallographic facets, impinged upon one another, and finally covered the entire substrate. Grains of energetically favorable crystallographic orientation selectively developed into the columnar structure. These columnar grains contained subgrains, dislocations, and twins. Remarkably different structures were observed for the Cu grown on large single-crystal grains. In this case epitaxial growth dominated the plating process. Low-surface-energy (111) Cu planes were frequently observed on plated Cu surfaces. Growth rates were a function of substrate orientation.

Micromechanics of multilayer printed circuit boards *by L. C. Lee, V. S. Darekar, and C. K. Lim, p. 711.* Analytical and experimental techniques are reported for the evaluation of micromechanical components in multilayer printed circuit boards. The concern in this investigation comes from the Z-axis thermal mismatch between epoxy-glass and copper that generates stresses when the board is subject to a temperature change. Finite-element modeling for both plated through-holes (PTH) and buried via (PV) structures is used to calculate the stresses in the copper barrel and at the via junctions. A simple experiment is designed to measure the thermomechanical strain in the PTH barrel. Also discussed are the PTH peel and PV pull techniques which have been used to characterize the barrel-laminate adhesion and the via junction strength.

Optimization of interconnections between packaging levels *by J. H. Kelly, C. K. Lim, and W. T. Chen, p. 719.* In large-scale integrated circuits, the interface between ceramic modules and the next level—epoxy-glass circuit boards or cards—contains a large number of pin arrays. Because the modules and the card are usually quite rigid and mechanically strong, the interface between the module and the card is commonly the weakest region in the assembly system. This interface is where the differential deformations between the two levels of packaging are accommodated. This paper describes a theoretical and experimental program to understand the loadings and stresses present, and to optimize the design of the connecting pin in order to distribute the stresses more evenly across the surfaces of the braze joint that connects the pin to the ceramic module. This work was done jointly by members of the East Fishkill and Endicott laboratories.

Immersion tin: Its chemistry, metallurgy, and application in electronic packaging technology *by Z. Kovac and K.-N. Tu, p. 726.* The surfaces in copper-plated through-holes in printed circuit boards for complex electronic packaging can be made solderable by immersion deposition of tin. The properties of the prepared surfaces vary from those of "white immersion tin," which is easily wetted by molten tin solder, to those of "gray immersion tin," which is nearly nonwettable. The wettability affects the electrical contact between the printed circuit board and the modules on it. In this paper, the rate law for tin deposition in the tin immersion plating bath is studied. Certain effects of chemical composition of the plating bath upon the character of the tin layer are investigated and the effects of thermal annealing of the plated surface upon the composition of the tin layer are determined. The differences in composition of white and gray immersion tin surface coatings are revealed by X-ray diffraction Rutherford backscattering spectroscopy and Auger electron spectroscopy.

Solderability tests on Sn, Cu, Cu_3Sn, and immersion tin surfaces are included.

High-temperature stability of a polyimide film *by R. Ginsburg and J. R. Susko, p. 735.* Polyimide (PMDA-ODA) films were analyzed by mass spectroscopy to determine their high-temperature stability. Using a high-resolution instrument, the identity of the low-molecular-weight evolved gases was confirmed. With a semiquantitative technique, the effect of a vacuum pre-bake was shown to reduce outgassing appreciably during subsequent treatment at high temperature. Subjection of the films to moisture did not affect their thermal stability. Low-temperature processing (240°C vs 400°C) reduced gaseous evolution by an order of magnitude.

Determination of Gafac in complex solution matrices *by S. A. Schubert, p. 741.* A new analytic method is described for determining the concentration of Gafac Re-610 (trademark of the GAF Corporation, New York, NY) in multicomponent solutions. This method utilizes a simple methylene chloride extraction to separate the Gafac from interfering chemical species, such as cupric sulfate. The ultraviolet absorbance of the methylene chloride extract is then measured at 276 nm and is shown to be proportional to the concentration of Gafac over the range of 1–170 ppm. However, this relationship is nonlinear except for concentrations less than 15 ppm. The limit of detection is 0.6 ppm and the relative precision at the 10-ppm level is ± 6%. Experiments to optimize and characterize various aspects of the analytical procedure are described, including determining the absorptivity of Gafac, measuring the distribution ratio, calculating extraction efficiencies, optimizing the extraction pH, and evaluating selected spectral interferences.

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The dynamical equations governing a lubricating film consisting of a gas film overlying a liquid film *by W. E. Langlois, p. 2.* The dynamical equations governing a two-phase lubricating configuration are derived. It is assumed that a gas film overlies a liquid film, both thin enough that the lubrication approximation may be used. The analysis leads to coupled Reynolds equations governing the pressure and the relative thickness of the two films. The coupling, which is determined by continuity of tangential stress across the gas-liquid interface, is considerably simplified if the shear viscosity of the liquid greatly exceeds that of the gas.

The stability of a colloidal suspension of coated magnetic particles in an aqueous solution *by D. Y. C. Chan, D. Henderson, J. Barojas, and A. M. Homola, p. 11.* Expressions for the magnetic, electrostatic and van der Waals interactions between isolated magnetic spheres which are coated with an inert material and immersed in an aqueous electrolyte solution are obtained and used to study the stability of a colloid of spheres in an electrolyte. Use is made of a simplified version of the theory of colloid stability of Derjaguin, Landau, Verwey, and Overbeek. We find that the colloidal dispersion becomes more stable as 1) the electrolyte concentration is decreased, 2) the radius of the magnetic spheres is decreased, or 3) the thickness of the inert layer is increased. In order to obtain stability with uncoated spheres, the spheres should have radii of about 5 nm. Such radii are typical of ferrofluids.

A dielectric loss investigation of moisture in epoxy-glass composites *by L. L. Marsh, D. C. Van Hart, and S. M. Kotkiewicz, p. 18.* Dielectric loss has been used to study moisture absorption-desorption equilibria and kinetics in epoxy-glass composites. Measurements were made at a temperature of 90°C and a frequency of 200 Hz to maximize sensitivity to interfacial or Maxwell-Wagner polarization. Exposure to various partial pressures of moisture at that temperature permitted a kinetics analysis from which an estimate was made of the diffusivity of water in the composites. Values of dielectric loss at saturation were used to establish a moisture/dielectric loss calibration at 90°C which can be used to estimate the macroscopic internal moisture content of coupon samples and printed circuit cards and boards. Dielectric loss measurements offer promise as a screening technique for resin-glass coupler development.

Cathodic delamination of methyl methacrylate-based dry film polymers on copper *by J. M. Atkinson, R. D. Granata, H. Leidheiser, Jr., and D. G. McBride, p. 27.* Studies of the bond degradation between a laminated organic coating and a copper substrate have been carried out using electrochemical techniques. The failure of the bond is attributed to a cathodic reaction which occurs under the coating. The rates of delamination are shown to be affected by delay time after exposure, temperature, applied potential, composition of the electrolyte, and surface abrasion prior to application of the coating.

A development of *APL2* syntax *by J. A. Brown, p. 37.* This paper develops the rules governing the writing of *APL2* expressions and discusses the principles that motivated design decisions.

A hardware sort-merge system *by N. Takagi and C.-K. Wong, p. 49.* The hardware sort-merge system which can sort large files rapidly is proposed. It consists of an initial sorter and a pipelined merger. In the initial sorter, record sorting is divided into two parts: key-pointer sorting and record rearranging. The pipelined merger is composed of several intelligent disks each of which has a simple processor and some buffers. The hardware sort-merge system can sort files of any size by using the pipelined merger repeatedly. The key-pointer sorting circuit in the initial sorter requires only unidirectional connections between neighboring cells, instead of the usual bidirectional ones. The initial sorter can also generate sorted sequences longer than its capacity so that the number of merging passes can be reduced. A new data management scheme is proposed to run all merging passes in a pipelined fashion.

Adaptive clustering algorithm *by L. V. O'Malley, p. 68.* Output data from many types of sensor systems (radar, radar warning, sonar, electro-optical, etc.) must be associated with one or more possible sources based on multiple observations of the data. This paper presents an algorithm that associates data with their source by simultaneous n-dimensional clustering of multiple data observations. The algorithm first orders the observations by successive nearest neighbor, in the n-dimensional Euclidean sense, from a defined starting point. Clusters are then isolated using a method derived from statistical decision theory. The algorithm's primary feature is its ability to perform clustering adaptively without any assumptions about the size, number, or statistical characteristics of the clusters. Since the algorithm was developed for radar warning system processing, a performance comparison with a well-known algorithm used in that field is included.

Novel method for analysis of printed circuit images *by J. R. Mandeville, p. 73.* To keep pace with the trend towards increased circuit integration, printed circuit patterns are becoming denser and more complex. A variety of automated visual inspection methods to detect circuit defects during manufacturing have been proposed. This paper describes a method which is a synthesis of the *reference-comparison* and the *generic-property* approaches that exploits their respective strengths and overcomes their respective weaknesses. It is based on the observation that the local geometric and global topological correctness of a printed circuit can be inferred from the correctness of simplified, skeletal versions of the circuit in a test image. These operations can be realized using

simple *processing elements* which are well suited for implementation in hardware.

The effects of wafer to wafer defect density variations on integrated circuit defect and fault distributions *by C. H. Stapper, p. 87.* A method for modeling the variations in defect levels in circuits produced on modern integrated circuit manufacturing lines is described in this paper. The effects on defect and fault distributions are derived. A deficiency in some previous yield models is eliminated.

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Microprocessors in brief *by R. C. Stanley, p. 110.* This paper presents a tutorial overview of the past, present, and future of microprocessors and describes the key elements of their structure and operation. It is intended to serve as a technical introduction to the rapidly expanding field of microprocessor and microcomputer technology and to provide an overview of what these elements are, what they can do, and how they do it. The origin and evolution as well as the basic principles of operation are discussed. Several different types of microprocessor are considered and examples of their application in the solution of real-world problems are given.

Architecture of a digital signal processor *by G. Ungerboeck, D. Maiwald, H.-P. Kaeser, P. R. Chevillat, and J. P. Beraud, p. 132.* A digital signal processor (DSP) is described which achieves high processing efficiency by executing concurrently four functions in every processor cycle: instruction prefetching from a dedicated instruction memory and generation of an effective operand, access to a single-port data memory and transfer of a data word over a common data bus, arithmetic/logic-unit (ALU) operation, and multiplication. Instructions have a single format and contain an operand, index control bits, and two independent operation codes called "transfer" code and "compute" code. The first code specifies the transfer of a data word over the common data bus, e.g., from data memory to a local register. The second determines an operation of the ALU on the contents of local registers. A fast free-running multiplier operates in parallel with the ALU and delivers a product in every cycle with a pipeline delay of two cycles. The architecture allows transversal-filter operations to be performed with one multiplication and ALU operation in every cycle. This is accomplished by a novel interleaving technique called ZIP-ing. The efficiency of the processor is demonstrated by programming examples.

Signal processor chip implementation *by J. P. Beraud, p. 140.* Very large microprocessors can now be integrated on a single chip; the integration eliminates packaging delays and is especially attractive for performance-oriented processors such as signal processors. This paper describes a semicustom signal processor chip designed jointly by the IBM France Essonnes and La Gaude laboratories. The logic is implemented from an optimized library of bipolar circuits. Layouts are compatible and designed to map data flow structures efficiently. Chip design time has been greatly reduced through the use of developed CAD tools tailored to our methodology. The design achieves twice the density that would be possible (with the same technology) with a masterslice. The chip's high performance has been verified with hardware; it provides enough computation power for 125 second-order filters with 8-kHz sampling of the input signal.

Voice-excited predictive coder (VEPC) implementation on a high-performance signal processor *by C. Galand, C. Couturier, G. Platel, and R. Vermot-Gauchy, p. 147.* In this paper, we discuss the implementation of a medium-bit-rate linear prediction baseband coder on an IBM bipolar signal processor prototype having a high processing capacity. We show that the implementation of our algorithm requires a processing load of 5 MIPS, with a program size of 5K instructions. We then discuss the application of our coder in a normal telephone environment, which requires mu-law to linear PCM conversion and other signal processing functions such as voice activity detection, automatic gain control, echo control, and error recovery. Quality evaluation tests are also reported which show that this type of coder, operating at 7.2 kbps, allows the transmission of telephone speech with communications quality. Moreover, obtained intelligibility scores and speaker recognition levels are high enough to demonstrate that this coder is a good candidate for telephony applications such as digital trunk transmissions, satellite speech communications, secure voice communications, and audio distribution systems.

Personal Instrument (PI)—A PC-based signal processing system *by G. Shichman, p. 158.* The Personal Computer (PC) technology has seen an enormous growth in the last two years. Although increasingly viewed as a major productivity tool, the PC is likely to be limited for computation-intensive tasks such as telecommunications and improved human-factors I/O. At the same time, there has been another evolving technology—VLSI realization of general-purpose signal processor (SP) engines which are capable of boosting the performance levels of standard PCs by almost two orders of magnitude. With SPs in PCs, we now see tremendous opportunities for distributing computation-intensive tasks away from high-performance mainframe computers; previously formidable tasks such as speech coding and recognition, pattern and scene analysis, spectral analysis, high bit-rate communication, and the like are now all computable by utilizing a single VLSI module embedded in any standard personal computer. This combination of a general-purpose CPU and superfast real-time coprocessor is likely to be key to the future functions and success of advanced workstations. A signal processing subsystem with real-time data acquisition and control capabilities has been developed for the IBM PC at the IBM Thomas J. Watson Research Laboratory and is the topic of this paper.

An approach to DFT calculations using standard microprocessors *by J. T. Rayfield and H. F. Silverman, p. 170.*

The use of the DFT as an everyday tool is now commonplace, principally due to advances in hardware technology. Special-purpose VLSI chips for signal processing are available. In this paper, we describe an approach which marries the Winograd Fourier Transform Algorithm (WFTA) with a state-of-the-art 16-bit general-purpose microprocessor for the purpose of DFT calculation. The heart of the approach is the real-input 240-point WFTA, which has been carefully optimized for time and space. In particular, an implementation for the 10-MHz M68000 executes in 10.8 ms. A simple hardware module is described which implements the optimized software. The use of the module for the inverse transform and for the complex case is also discussed. Advantages to the approach taken in this paper are the low cost/performance ratio and the general-purpose nature of the system that allows many non-signal-processing functions to be performed by the microprocessor.

Image processing applications for geologic mapping *by M. Abrams, A. Blusson, V. Carrere, T. Nguyen, and Y. Rabu, p. 177.* The use of satellite data, particularly Landsat images, for geologic mapping provides the geologist with a powerful tool. The digital format of these data permits applications of image processing to extract or enhance information useful for mapping purposes. Examples are presented of lithologic classification using texture measures, automatic lineament detection and structural analysis, and use of registered multisource satellite data. In each case, the additional mapping information provided relative to the particular treatment is evaluated. The goal is to provide the geologist with a range of processing techniques adapted to specific mapping problems.

Parameter reduction and context selection for compression of gray-scale images *by S. J. P. Todd, G. G. Langdon, Jr., and J. Rissanen, p. 188.* In the compression of multilevel (color or gray) image data, effective compression is obtained economically by judicial selection of the predictor and the conditioning states or contexts which determine what probability distribution to use for the prediction error. We provide a cost-effective approach to the following two problems: (1) to reduce the number of coding parameters to describe a distribution when several contexts are involved, and (2) to choose contexts for which variations in prediction error distributions are expected. We solve Problem 1 (distribution description) by a *partition* of the range of values of the outcomes into *equivalence classes,* called *buckets.* The result is a special *decomposition* of the error range. Cost-effectiveness is achieved by using the many contexts only to predict the bucket (equivalence class) probabilities. The probabilities of the value within the bucket are assumed to be independent of the context, thus enormously reducing the number of coding parameters involved. We solve Problem 2 (economical contexts) by using the *buckets* of the surrounding pixels as components of the conditioning class. The bucket values have the desirable properties needed for the error distributions.

Regenerative simulation methods for local area computer networks *by P. J. Haas and G. S. Shedler, p. 194.* Local area computer network simulations are inherently non-Markovian in that the underlying stochastic process cannot be modeled as a Markov chain with countable state space. We restrict attention to local network simulations whose underlying stochastic process can be represented as a generalized semi-Markov process (GSMP). Using "new better than used" distributional assumptions and sample path properties of the GSMP, we provide a "geometric trials" criterion for recurrence in this setting. We also provide conditions which ensure that a GSMP is a regenerative process and that the expected time between regeneration points is finite. Steady-state estimation procedures for ring and bus network simulations follow from these results.

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Advanced bipolar transistor modeling: Process and device simulation tools for today's technology *by R. W. Knepper, S. P. Gaur, F.-Y. Chang, and G. R. Srinivasan, p. 218.* A series of programs have been developed and linked together for doing advanced transistor modeling. The strategy begins with a process modeling program, SAFEPRO, for predicting two-dimensional impurity profiles. These are input to a two-dimensional device physics modeling program, 2DP, for generating device electrical characteristics. A three-dimensional distributed device model is then assembled by a model generator program (MGP) which, in turn, is used to derive a lumped equivalent-circuit model for numerical circuit analysis. The tools make it possible to do process sensitivity studies, perform process and device optimization, and provide early feedback on technology performance. The approach has recently been used to examine and compare various technologies at IBM.

Two-dimensional process modeling: A description of the SAFEPRO program *by R. R. O'Brien, C. M. Hsieh, J. S. Moore, R. F. Lever, P. C. Murley, K. W. Brannon, G. R. Srinivasan, and R. W. Knepper, p. 229.* This paper describes the development, testing, and application of a finite element program which simulates the processes used in manufacturing transistors. The profiles calculated by the program can be input directly into a device analysis program. The paper includes a description of the physical phenomena modeled and explains the choice of the particular numerical methods used to solve the resulting equations. It shows an example of the application of the program to the design and sensitivity study of a submicrometer shallow-junction bipolar transistor and presents results obtained when an oxide is grown on boron-doped silicon.

Two-dimensional device simulation program: 2DP *by S. P. Gaur, P. A. Habitz, Y.-J. Park, R. K. Cook, Y.-S. Huang, and L. F. Wagner, p. 242.* Mathematical details of a two-dimensional semiconductor device simulation program

are presented. Applicability of the carrier transport model to shallow junction bipolar transistors is discussed. Use of this program to optimize device structures in new bipolar technology is illustrated by presenting calculated device characteristics for variations in a few selected process conditions. Software links that automatically transfer data from a two-dimensional process simulation program and to a quasi-three-dimensional device equivalent circuit model generation program are also discussed.

The generation of three-dimensional bipolar transistor models for circuit analysis *by F.-Y. Chang and L. F. Wagner, p. 252.* The results of a two-dimensional bipolar numerical device-analysis program are processed by identifying three regions of the transistor: the intrinsic transistor, the sidewall transistor, and the extrinsic base collector diode. The key parameters which describe each of these regions are extracted using a linking program and fed into a quasi-three-dimensional device analysis program referred to here as the Model Generation Program (MGP). The MGP first generates a large equivalent-circuit distributed network which simulates the three-dimensional geometry of an actual transistor. This distributed network is then analyzed using the existing Advanced Statistical Analysis Program (ASTAP) for circuit analysis. Finally the MGP extracts parameters from the ASTAP analysis to characterize the elements of a lumped-model equivalent circuit, which is then suitable for the circuit design of large-scale integrated circuit chips. The MGP is sufficiently flexible that transistors with a variety of geometries can be generated without repeating the two-dimensional analysis.

FEDSS—A 2D semiconductor fabrication process simulator *by L. Borucki, H. H. Hansen, and K. Varahramyan, p. 263.* The main features of the finite element semiconductor process simulator FEDSS are described, with emphasis on a recently added capability for generalized 2D oxidation with impurity redistribution in oxide and silicon. Examples are given that demonstrate the ability of the program to oxidize various structures using a model based on steady-state oxidant diffusion and incompressible viscous oxide flow. Impurity profiles and contours are also shown in both neutral and oxidizing ambients, along with several comparisons with data or with the program SUPREM II.

VLSI wiring capacitance *by P. E. Cottrell and E. M. Buturla, p. 277.* Accurate prediction of device current and the capacitance to be driven by that current is key to the design of integrated logic and memory circuits. A finite-element algorithm is described which simulates the capacitance of structures with general shape in two or three dimensions. Efficient solution of the linear equations is provided by the incomplete Cholesky conjugate gradient method. The model is used to simulate the wiring capacitance of a 1.25-micrometer VLSI technology. The predicted capacitances of closely spaced first-metal polycide-gate and second-metal conductors used in this technology agree with measured results. The simulated three-dimensional capacitance of a second-metal line crossing a first-metal line is twice that found when estimated by two-dimensional models. The effect of line-to-line capacitance on the noise margin of logic circuits and on the signal in a dynamic RAM is examined. This capacitance presents a limit to wiring density for logic circuits and is a significant signal detractor in dynamic RAMs with closely spaced metal or diffused bit lines.

Semiconductor device simulation using generalized mobility models *by S. E. Laux and R. G. Byrnes, p. 289.* A method for discretizing the semiconductor transport equations using generalized mobility models is developed as an extension of the Scharfetter-Gummel finite difference approach. The method is sufficiently general to be applicable to nearly arbitrary empirical mobility models (including those for MOS surface effects) and may be used on a variety of mesh types in two or three dimensions. The impact of generalized mobility models on the sparsity of our resulting discrete equations is discussed. Convergence rate of a Newton's method linearization of the nonlinear system of equations is measured and interpreted. Some computational results from a study of short-channel MOSFETs are presented to illustrate the approach.

Animation and 3D color display of multiple-variable data: Application to semiconductor design *by E. J. Farrell, S. E. Laux, P. L. Corson, and E. M. Buturla, p. 302.* The increasing complexity of digital simulations requires more effective techniques to display and interpret the voluminous outputs. Advanced digital processing workstations and high-resolution color monitors permit a wide range of new techniques for use in examining the global characteristics of each output variable and their interrelationships with other variables. In this investigation, animation, 3D display, and multiple-window imaging have been shown to be effective in interpreting multiple-variable data sets, both scalar and vector. These display methods are used in the solution of two specific semiconductor design problems: the avalanche breakdown of an n-MOSFET and an alpha particle hit on an npn transistor. With these techniques the user can more fully utilize the results of these long and costly computations, making these methods a powerful addition to existing techniques for imaging data.

An experimental comparison of the head/disk interface dynamics in 5¼- and 8-inch disk drives *by G. Bouchard, D. B. Bogy, and F. E. Talke, p. 316.* A laser Doppler vibrometer is used to measure the head/disk interface dynamics in computer disk drives. The stability of the head under steady operating conditions is compared between a 5¼-inch and two different 8-inch "Winchester" drives. In the larger drives, high-frequency vibrations (between 5 and 10 kHz) are detected on the slider which are not present in the smaller drive. These vibrations have amplitudes on the order of magnitude of the head/disk spacing and are related to the

rolling and pitching modes of the slider. The vibrations of the disk, suspension, and actuator arm are also investigated and correlated with the results obtained on the slider.

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Analysis of manufacturing systems by the Research Queueing Package *by W.-M. Chow, E. A. MacNair, and C. H. Sauer, p. 330.* Many aspects of manufacturing systems can be analyzed using simulation to model the system's behavior. The Research Queueing Package (RESQ) is a tool developed to construct and solve models of systems with jobs contending for service from many resources. The capabilities of RESQ are described in order to understand the model elements which are available for representing manufacturing systems. Then an analysis of several work-in-process (WIP) policies is presented using RESQ models solved by simulation. Four WIP management policies are analyzed and compared for a future assembly manufacturing line: (1) a push system, (2) a pull system, (3) a transfer line, and (4) a closed loop system.

Integrated Manufacturing Modeling System *by H. Engelke, J. Grotrian, C. Scheuing, A. Schmackpfeffer, W. Schwarz, B. Solf, and J. Tomann, p. 343.* The objective of the Integrated Manufacturing Modeling System (IMMS) project was to build a generic software package for manufacturing modeling. The package allows interactive model building, testing, and experimentation. IMMS integrates the fundamental components of modeling, namely system description, data acquisition and management, graphic input and output, and performance simulation. The fundamental idea is to describe the flow of information, materials, and resources by using parametric standard model building blocks. Inputting is done by placing function symbols on a graphic screen and by filling in blanks for parameter data. The output includes all common performance measures, such as utilization and work in process (WIP), in graphic form. The simulation language used to implement the model building blocks is RESQ2. The Integrated Manufacturing Modeling System combines the advantage of simulation modeling with the advantages of end user programming capability. Simulation results allow intelligent decision making based on analysis (instead of intuitive experience), and an end user package reduces the turnaround time for modeling and eliminates the need for specialized programming skill. All this translates into faster and better-quality manufacturing system design and operation.

An algorithm for carrier routing in a flexible material-handling system *by C. L. Haines, p. 356.* Flexible material-handling systems for manufacturing have the capability of moving articles or carriers between process stations in different sequences. The traditional method for controlling the routing of carriers is to determine, in advance, all of the useful paths within the system, and store the information in a central computer until needed. This article describes a routing algorithm that determines the correct turns a carrier should make while it is in motion. Making routing decisions does not require a global knowledge of the system's layout, because a method of numbering stations within the system which reflects its natural path of flow is employed. A brief survey of contemporary material-handling mechanisms is provided. The implementation of the algorithm using distributed controllers is discussed.

Precise manipulation with endpoint sensing *by R. H. Taylor, R. L. Hollis, and M. A. Lavin, p. 363.* This paper describes recent work on manipulation strategies that rely on "coarse-fine" robot hardware and direct sensing of part-workpiece relationships. The experiments reported use an extremely precise, high-bandwidth planar "wrist" and an industrial vision system to perform accurate alignment of small parts. The system architecture, experimental hardware, and programming methods employed are all discussed.

On the analysis and design of CUSUM-Shewhart control schemes *by E. Yashchin, p. 377.* In recent years cumulative sum (CUSUM) control charts have become increasingly popular as an alternative to Shewhart's control charts. These charts use sequentially accumulated information in order to detect out-of-control conditions. They are philosophically related to procedures of sequential hypothesis testing (the relation being similar to that existing between Shewhart's charts and classical procedures for hypothesis testing). In the present paper we present a new approach to design of CUSUM-Shewhart control schemes and analysis of the associated run length distributions (under the assumption that the observations correspond to a sequence of independent and identically distributed random variables). This approach is based on the theory of Markov chains and it enables one to analyze the ARL (Average Run Length), the distribution function of the run length, and other quantities associated with a CUSUM-Shewhart scheme. In addition, it enables one to analyze situations in which out-of-target conditions are not present initially, but rather appear after a substantial period of time during which the process has operated in on-target mode (steady state analysis). The paper also introduces an APL package, DARCS, for design, analysis, and running of both one- and two-sided CUSUM-Shewhart control schemes and gives several examples of its application.

Short-term production scheduling of an automated manufacturing facility *by S. B. Gershwin, R. Akella, and Y. F. Choong, p. 392.* We describe a new implementation of the Kimemia-Gershwin hierarchical policy for the real-time scheduling of flexible manufacturing systems. Major improvements result at all three levels of the policy. The algorithm simplification, resulting in substantial reductions of off-line and on-line computation time, is reported, as is the improvement in performance through the elimination of chattering. Simulation results based on a detailed model of a printed circuit card assembly facility are summarized.

Scheduling algorithms for flexible flow lines *by R. J. Wittrock, p. 401.* This paper discusses scheduling algorithms

for a certain kind of manufacturing environment, called the "flexible flow line." Two scheduling problems are considered. "Loading" decides when each part should be loaded into the system. "Mix allocation" selects the daily part mix. The goals are to maximize throughput and reduce WIP. New heuristic algorithms specially suited to solve these problems in the context of a flexible flow line are described. The paper also discusses experience with the use of an experimental implementation of these algorithms to solve such problems arising in a real production line.

A prototype manufacturing knowledge base in Syllog *by C. Fellenstein, C. O. Green, L. M. Palmer, A. Walker, and D. J. Wyler, p. 413.* This paper describes a prototype knowledge base for manufacturing planning, which we have built using a knowledge system shell called Syllog. We describe a Tester Capacity Planning and Yield Analysis task, knowledge needed for a part of the task, and the use of the knowledge in the Syllog system. We report that the sometimes difficult process of knowledge acquisition turned out, in this case, to be straightforward. Knowledge acquisition and knowledge use are done in the same language in Syllog.

Large-scale scientific application programs in chemistry and physics on an experimental parallel computer system *by G. Corongiu and J. H. Detrich, p. 422.* We present and discuss an experimental distributed system consisting of two IBM 4341s, an IBM 4381, and ten FPS-164 attached processors, configured to allow parallel execution of a single large-scale calculation on multiple processors. A number of our application programs have been converted to run on this system, and the strategy for this conversion is outlined in sufficient detail to facilitate the development of tests using other scientific and engineering computer application programs. Our tests, though limited to certain biochemical and physicochemical problems, demonstrate the versatility, flexibility, and accessibility of this system, and we find performance comparable to that of today's supercomputers, which suggests that our approach can provide a practical answer to many large-scale computer applications.

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Preface *by W. F. Voit, Jr., p. 442.*

Design and implementation of the SELECTRIC System/2000 *by T. H. Williams, p. 443.* This paper presents an overview of the papers in this issue of the *IBM Journal of Research and Development* covering the design and implementation of the ®SELECTRIC System/2000 Typewriter/Printer products. The SELECTRIC System/2000 products comprise a nonimpact typewriter and printer, two impact typewriters, and an impact printer which use printwheel technology. The development approach for the SELECTRIC System/2000 products, which included design for automation, introduction of new technologies, and product development concurrent with manufacturing, was accomplished by the use of common architecture, hardware, and software.

Resistive ribbon thermal transfer printing: A historical review and introduction to a new printing technology *by K. S. Pennington and W. Crooks, p. 449.* This paper describes a new high-quality thermal transfer printing process in which a printhead consisting of a linear array of small-diameter electrodes produces highly localized Joule heating of a resistive thermal transfer printing ribbon. The heat generated in the resistive ribbon results in the melting of a thermoplastic ink which is then transferred to a printable medium, such as paper, by contact. The origins of the technology in IBM are discussed, together with a description of the resistive ribbon materials and structure, the printhead, and some experimental printer performance values.

Implementation of the resistive ribbon technology in a printer and correcting typewriter *by S. Applegate, J. Bartlett, A. Bohnhoff, A. Campbell, and J. Molloy, p. 459.* This paper describes key technology implementation details and performance characteristics of a printer and typewriter using the resistive ribbon technology. The work describes the first commercial application of this print and correction technology. Key parameters necessary for proper system function such as current, various forces, velocities, and component integration are discussed. The rationales behind various compromises and problem solutions are given. A discussion of the characteristics of the print produced, along with application strengths and weaknesses, completes the paper.

Characterization of a resistive ribbon thermal transfer printing process *by T. G. Twardeck, p. 470.* Resistive ribbon thermal transfer printers transfer ink from a ribbon to paper as the result of localized Joule heating of the ribbon structure. For this printing process, this paper discusses the voltage-versus-current response of the electrode-ribbon current path, the temperature distributions throughout the ribbon structure, and the correlation of print response with electrical input power and average ribbon temperatures. Nominal input power per electrode is approximately 190 mW. For input power near this level, thermal models predict that ribbon materials which pass directly under energized electrodes reach the highest temperatures; the hottest zone in the ribbon surrounds the composite-aluminum interface. Approximately 0.1 mm downstream from the electrodes, the heated ribbon materials come to nearly constant temperature. The area of the printed image correlates with this average ribbon temperature and input power.

Development of a membrane switch-type full-travel tactile keyboard *by S. F. DeFosse, G. T. Williams, D. A. Gostomski, Jr., and R. H. Cobb, p. 478.* This paper describes the approaches to design and the rationale that successfully satisfied the requirements for a full-travel keyboard with usage exceeding 10 million actuations per character, satisfactory

N-key roll-over, and phantom key control. Emphasis was placed on technical understanding of the effects of all material and design decisions. Interactions among design, material, and processing variables were revealed through statistical parameter modeling and environmental exposure studies. This knowledge facilitated the control of critical parameters to permit an order-of-magnitude reduction of actuation forces and tolerances. Product reliability was achieved through evaluation, environmental protection features, and stringent process controls. This paper highlights the design, materials, and processing aspects of the membrane switch developed for low-force keyboard applications. It also discusses effects of environmental factors on the individual components and overall system function.

System control for a printwheel typewriter *by R. D. Mayo, p. 488.* This paper presents the design goals and architecture of the IBM ®WHEELWRITER typewriters. Some of the development efforts and resulting technical innovations, such as a unique print hammer design which minimizes sensitivities to current variations, are discussed. Included is a discussion of a variable-reluctance stepper motor driver that has selectable damping. A novel scheme for initializing the printwheel and escapement motors is given; this includes sensing the font weight. The electronic architecture of the typewriter and the design of a simplified algorithm to handle the many different keyboards that can be attached to the machine with a minimum amount of data storage are explained.

System controls for a resistive ribbon printer *by A. Bohnhoff, D. Croley, S. Dyer, T. Green, R. Maddox, and L. Struttmann, p. 494.* The system controls for a printer using the resistive ribbon print technology involve conventional requirements, such as moving the print mechanism relative to the paper, with a new requirement, controlling the electrical energy to the ribbon, an electrothermal component. Other special requirements are dictated by using the same ribbon for hard copy print/erase while ensuring that the print and erase operations are acceptable to the user. This paper discusses the design and performance of the system controls for a resistive ribbon printer that was developed for use in an interactive typewriter application and as an output printer for a personal computer.

Ink temperatures in resistive ribbon thermal transfer printing *by T. C. Chieu and O. Sahni, p. 509.* A knowledge of ink temperatures is important in thermal transfer printing technologies. This paper reports on an experimental technique which uses an infrared radiometric microscope to measure the temperature of ink deposited by the resistive ribbon process on transparent substrates. A detailed examination has been made of the spatial and temporal profiles of ink temperatures as a function of input current, printing speed, substrate materials, and number of active electrodes. The results on a ®Kapton substrate permit estimation of the ink temperatures reached during printing on paper. The peak ink temperatures are observed to depend linearly on input current and inversely on an approximately linear function of writing speed from 2 to 8 inches per second. Based on a phenomenological model, these results lead to a functional relationship among speed, print current, and ink temperature during printing. The model permits projections to be made of the current required over a wide range of printing speeds.

Electrical properties of resistive ribbon *by K. K. Shih and D. B. Dove, p. 519.* In resistive ribbon thermal transfer printing, a printhead consisting of an array of electrodes passes current into a thin ribbon to generate heat for transferring ink to paper. The ribbon is made of a polymeric material containing carbon black so as to be conducting, and has aluminum deposited on one side of the ribbon for a base contact. In this paper, the electrical conduction processes within the ribbon are discussed. Current-voltage measurements have been made with electrodes of various types in order to separate effects due to contact resistance, aluminum/resistive ribbon interfacial resistance, and bulk conduction in the resistive ribbon. Measurements have been made over a range of frequency and temperature to determine the basic conduction mechanisms. A model of conduction is presented that is in qualitative agreement with the data.

Thermal behavior of resistive ribbon for single-stylus excitation *by R. A. Laff and C. D. Makowka, p. 527.* This paper provides a quantitative description of the heating and cooling behavior of the resistive ribbon used in resistive ribbon thermal transfer printing. Since the focus is upon the ribbon, this description has been facilitated by substituting a single, tapered tungsten stylus as a model for a single printhead element. The experiment used an infrared spot pyrometer to measure ribbon surface temperatures downstream from the stylus while a laminate of ribbon and paper was continuously moved beneath the stylus and subjected to current pulses. Measured cooling rates under steady-state excitation at different ribbon velocities showed a behavior consistent with two simple analytic models which describe heat loss into the stylus during heating and two-dimensional diffusion into a half-plane during cooling. A detailed, time-dependent computer simulation using finite-element methods was used to provide a more detailed description of the process by taking into account the local geometry of the heat input distribution and the layered nature of the ribbon-paper laminate. The resulting three-dimensional temperature distributions are given for the steady-state case.

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Adaptive cross-parity (AXP) code for a high-density magnetic tape subsystem *by A. M. Patel, p. 546.* This paper describes an error-correction system, called adaptive cross-parity (AXP) code, for the IBM 3480, a new high-density 18-track tape storage subsystem. Redundancy is applied to two interleaved sets of nine tracks in the same proportion as that in the previous IBM 3420 tape machines.

The coding structure, however, is simpler, for it avoids the complex computations of Galois fields. The coding structure is based on a concept of interacting vertical and cross-parity checks, where the cross-parity checks span both sets of tracks and are used in either set in an adaptive manner. As a result, the overall error-correcting capability is substantially improved without increasing the redundancy. Decoding, in which simple parity equations are processed, is designed to progress iteratively. By means of adaptive use of redundancy, the new method corrects up to three known erroneous tracks in any one set of nine tracks and up to four known erroneous tracks in the two sets together. The code also identifies the first unknown erroneous track in each of the two sets, and subsequently identifies the second unknown erroneous track in one of the two sets while providing correction for all these tracks. The result is generalized for a system with any number of tracks divided into a multiple number of unequal sets.

Write equalization in high-linear-density magnetic recording *by R. C. Schneider, p. 563.* For many years, equalization has been used on the read side of a magnetic-recording channel to obtain a desired signal shape at the detector. Compensation on the write side has, for the most part, been limited to moving transition locations to offset read-signal peak shifts. This paper presents a new method of equalization on the write side through the addition of pulses at strategic locations on the write waveform. The resulting write current continues to be a two-level signal, so ac bias is not required. A linear transfer function can be derived for these write equalizers. This enables the recording-channel designer to partition the equalization more optimally between the write and read sides. The principal benefit of write equalization is that the read-flux-amplitude differences between high and low densities are significantly reduced. This permits maximum use of the linear operating region of the magnetoresistive read head. By providing high-frequency boosts on the write side, write equalization can reduce high-frequency noises at the read detector. Test results of channel linearity, as well as read signal waveshapes, are presented.

Image processing by simulated annealing *by P. Carnevali, L. Coletti, and S. Patarnello, p. 569.* It is shown that simulated annealing, a statistical mechanics method recently proposed as a tool in solving complex optimization problems, can be used in problems arising in image processing. The problems examined are the estimation of the parameters necessary to describe a geometrical pattern corrupted by noise, the smoothing of bi-level images, and the process of halftoning a continuous-level image. The analogy between the system to be optimized and an equivalent physical system, whose ground state is sought, is put forward by showing that some of these problems are formally equivalent to ground state problems for two-dimensional Ising spin systems. In the case of low signal-to-noise ratios (particularly in image smoothing), the methods proposed here give better results than those obtained with standard techniques.

Jitter accommodation in token-passing ring LANs *by R. J. S. Bates and L. A. Sauer, p. 580.* In a token-passing ring Local Area Network (LAN) each message accumulates phase jitter as it travels around the ring. Unlike typical digital transmission systems, which tend to have random data traffic, ring systems carrying computer-generated traffic may have long strings of repetitive-pattern data. This traffic produces a jitter amplitude which is a function of the message statistics and the transmission characteristics of the physical layer. For the system to be stable, this jitter must be controlled. This paper describes the repetitive-pattern jitter generation and accumulation process and gives a methodology for designing the physical layer components to accommodate it.

Analysis of the holding current in CMOS latch-up *by H. Matino, p. 588.* The holding current in CMOS latch-up with or without well and/or substrate bias has been examined. Measurements indicate that the holding current increases significantly with reverse bias and low shunting base resistance. It is shown that a previous equation for the holding current is inaccurate, and a new equation for holding current with bias is presented.

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Knowledge systems: Principles and practice *by A. Walker, p. 2.* We describe what is expected of a knowledge-based expert system, and the components from which such a system is constructed. We give a view of how an interplay between principles and practice has helped the knowledge system field to develop, and we give simple examples to show that reasoning techniques based on formal logic are now starting to provide a useful coupling between scientific and engineering work in the field. The examples are about logic programming, knowledge representation, judgmental reasoning, and about three methods by which a system can acquire the knowledge it needs.

A continuous real-time expert system for computer operations *by R. L. Ennis, J. H. Griesmer, S. J. Hong, M. Karnaugh, J. K. Kastner, D. A. Klein, K. R. Milliken, M. I. Schor, and H. M. Van Woerkom, p. 14.* The Yorktown Expert System/MVS Manager (or YES/MVS for short) is a continuous real-time expert system that exerts active control over a computing system and provides advice to computer operators. YES/MVS provides advice on routine operations and detects, diagnoses, and responds to problems in the computer operator's domain. This paper discusses the YES/MVS system, its domain of application, and issues that arise in the design and development of an expert system that runs continuously in real time.

Interfaces for knowledge-base builders' control knowledge and application-specific procedures *by P. Hirsch, W. Katke, M. Meier, S. Snyder, and R. Stillman, p. 29.* Expert System Environment/VM is an expert system shell—a general-purpose system for constructing and executing expert system applications. An application expert has both factual knowledge about an application and knowledge about how that factual knowledge should be organized and processed. In addition, many applications require application-dependent procedures to access databases or to do specialized processing. An important and novel part of Expert System Environment/VM is the technique used to allow the expert or knowledge-base builder to enter the control knowledge and to interface with application-dependent procedures. This paper discusses these high-level interfaces for the knowledge-base builder.

A theory for the representation of knowledge *by F. Guenthner, H. Lehmann, and W. Schönfeld, p. 39.* How to represent knowledge is one of the key questions in the construction of expert systems. Its solution depends on a number of factors, the most important of which are how knowledge is to be acquired and how it is to be used. Since we are interested in the use of natural language for communication with computers, we require from a formalism suggested for knowledge representation that it be suitable as a target for the systematic translation from natural language expressions. We want to propose a theory, called *Discourse Representation Theory (DRT),* which was originally developed by Kamp to analyze natural language discourse, as a means to represent knowledge in an expert system. With Discourse Representation Theory it has been possible to solve certain cases of contextual relations which have puzzled linguists and logicians for a long time. In this paper we give a precise definition of DRT and describe the rules used to translate from natural language to Discourse Representation Structures (DRSs), the central notion of the theory. We show how the notation used in DRT relates to standard predicate logic and define its deductive theory. We also outline ways of implementing DRT and the proof procedures we intend to use.

Implementing a semantic interpreter using conceptual graphs *by J. F. Sowa and E. C. Way, p. 57.* A parser applies grammar rules to generate a parse tree that shows the syntactic structure of a sentence. This paper describes a semantic interpreter that starts with a parse tree and generates conceptual graphs that represent the meaning of the sentence. To generate conceptual graphs, the interpreter joins *canonical graphs* associated with each word of input. The result is a larger graph that represents the entire sentence. During the interpretation, the parse tree serves as a guide to show how the graphs are joined. Both the front-end parser and the back-end semantic interpreter are written in the Programming Language for Natural Language Processing (PLNLP).

Conceptual graphs for semantics and knowledge processing *by J. Fargues, M.-C. Landau, A. Dugourd, and L. Catach, p. 70.* This paper discusses the representational and algorithmic power of the conceptual graph model for natural language semantics and knowledge processing. Also described is a Prolog-like resolution method for conceptual graphs, which allows one to perform deduction on very large semantic domains. The interpreter that we have developed is similar to a Prolog interpreter in which the terms are any conceptual graphs and in which the unification algorithm is replaced by a specialized algorithm for conceptual graphs.

Storing and evaluating Horn-clause rules in a relational database *by G. van Emde Boas and P. van Emde Boas, p. 80.* This paper describes a practical approach to storing and evaluating Horn-clause rules in a relational database system. The intention is to give a complete outline of what needs to be added to an existing relational database system to allow it to support full logic programming functions. Implementation issues for each new function are discussed. We show how Horn-clause rules can be translated into database commands without recourse to semantics and how their evaluation can be performed in the database itself. This brings the complete logic programming environment within reach of the database management system, allowing data and rule sharing, concurrency control, recovery procedures, etc., to be used. New is that the complete logic programming environment is incorporated into the database system. IBM Business System 12, extended in this way, may be a suitable vehicle for expert system applications.

Structures of rule-based belief functions *by W. F. Eddy and G. P. Pei, p. 93.* Shafer's theory of evidential reasoning has recently received much attention as a possible model for probabilistic reasoning in expert system applications. This paper discusses the particular difficulties of implementing Shafer's belief functions in the context of the most common form of expert system, rule-based systems. The two most important problems are: the representation of the expert's subjective degrees of belief corresponding to his expressed rules, and the computational complexity of the inference mechanism for combining evidence. We argue that a potential approach for dealing with both problems is given by introducing constraints on the structure of the belief functions. These constraints, along with the expressed rules and the elicited belief values, form the expert's total knowledge.

An experimental computer architecture supporting expert systems and logic programming *by H. Diel, N. Lenz, and H. M. Welsch, p. 102.* This paper describes a set of function primitives which have been designed for support of expert systems and logic programs. The functions could be offered as part of the computer architecture by implementing them in microcode and partially in hardware. The functions are primarily (but not exclusively) oriented towards support of logic programming languages such as Prolog for implementing expert systems. Particular emphasis is given to supporting the parallel execution of expert system applications by multiple processors. The concepts described are based on the Concurrent Data Access Architecture (CDAA). It is shown that OR-parallelism, as well as AND-parallelism, can be supported.

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New scalar and vector elementary functions for the IBM System/370 *by R. C. Agarwal, J. W. Cooley, F. G. Gustavson, J. B. Shearer, G. Slishman, and B. Tuckerman, p. 126.* Algorithms have been developed to compute short- and long-precision elementary functions: SIN, COS, TAN, COTAN, LOG, LOG10, EXP, POWER, SQRT, ATAN, ASIN, ACOS, ATAN2, and CABS, in scalar (28 functions) and vector (22 functions) mode. They have been implemented as part of the new VS FORTRAN library recently announced along with the IBM 3090 Vector Facility. These algorithms are essentially table-based algorithms. An important feature of these algorithms is that they produce bitwise-identical results on scalar and vector System/370 machines. Of these, for five functions the computed value result is always the correctly rounded value of the infinite-precision result. For the rest of the functions, the value returned is one of the two floating-point neighbors bordering the infinite-precision result, which implies exact results if they are machine-representable. For the five correctly rounded elementary functions, scalar and vector algorithms are designed independently so as to optimize performance in each case. For other functions, the bitwise-identical constraint leads to algorithms which compromise between scalar and vector performance. We have been able to design algorithms where this compromise is minimal and thus achieve very good performance on both scalar and vector implementations. For our test measurements on high-end System/370 machines, our scalar functions are always faster (sometimes by as much as a factor of 2.5) as compared to the old VS FORTRAN library. Our vector functions are usually two or three times faster than our scalar functions.

Fourier transform and convolution subroutines for the IBM 3090 Vector Facility *by R. C. Agarwal and J. W. Cooley, p. 145.* A set of highly optimized subroutines for digital signal processing has been included in the Engineering and Scientific Subroutine Library (ESSL) for the IBM 3090 Vector Facility. These include FORTRAN-callable subroutines for Fourier transforms, convolution, and correlation. The subroutines are carefully designed and tuned for optimal vector and cache performance. Speedups of up to 9½ times over scalar performance on the 3090 have been obtained.

A vectorizing Fortran compiler *by R. G. Scarborough and H. G. Kolsky, p. 163.* This paper describes a vectorizing Fortran compiler for the IBM 3090 Vector Facility. Opportunities for vectorization are investigated for eight levels of DO-loop nesting. Recurrences in inner loops do not prevent vectorization of outer loops. A least-cost analysis determines from the opportunities identified which specific vectorization will result in the fastest execution. The normal optimization phases of the compiler produce much of the information needed for the vectorization analysis.

Seismic migration on the IBM 3090 Vector Facility *by J. Gazdag, G. Radicati, P. Sguazzero, and H.-H. Wang, p. 172.* Seismic prospecting aims at determining the structure of the earth from indirect measurements. Acoustic wave fields are generated at the surface, penetrate the earth, and are backscattered by the earth's inhomogeneities. The data recorded at the surface are processed in a complex sequence of steps among which seismic migration plays an important role. This is a wave depropagation process that permits the localization in depth of the origin of the diffraction events measured (in time) at the surface. This paper presents an overview of the major wave-equation migration methods. The most frequently executed algorithms or kernels on which the execution speed depends most crucially are given particular attention. The speedup resulting from scalar-to-vector formulation is presented over wide ranges of dimensionality for linear tridiagonal equation solvers, Fourier Transforms, and convolution operations. The vectorizability and resulting speedup are also addressed in the case of migration schemes known as the Phase-Shift Method and the Phase Shift Plus Interpolation (PSPI) Method. It is shown that Fourier domain migration based on the phase-shift concept lends itself conveniently to multilevel parallelism on the 3090 Vector Facility (VF): vectorization of the innermost loops and

concurrent processing in the outer loops by means of the VS FORTRAN Version 2 Multitasking Facility.

Parallel iterative linear solvers for oil reservoir models *by I. Efrat and M. Tismenetsky, p. 184.* This paper suggests a new algorithm for solving sparse linear systems which is readily parallelized and is very efficient for matrices arising in such domains as reservoir modeling. The algorithm is, in fact, a variant of the incomplete block factorization technique, accelerated by Biconjugate Gradient iterations or by another acceleration method. Implementation on a vector computer such as the IBM 3090 Vector Facility is described. We also suggest some refinements of known preconditioning methods enabling their parallel computation. Numerical experiments are presented to display the performance of the suggested methods. Special attention is given to fully implicit, multiphase models which yield asymmetrical systems.

Monte Carlo photon transport on a vector supercomputer *by W. R. Martin, P. F. Nowak, and J. A. Rathkopf, p. 193.* The use of "event-based" algorithms for particle transport Monte Carlo methods has allowed the successful adaptation of these methods to vector supercomputers. An alternative algorithm for the specific application of photon transport in an axisymmetric inertially confined fusion plasma has been developed and implemented on a vector supercomputer. The new algorithm is described; its unique features are discussed and compared with existing vectorized algorithms for Monte Carlo. Numerical results are presented illustrating its efficiency on a vector supercomputer, relative to an optimized scalar Monte Carlo algorithm that was developed for this purpose.

Chemical and mechanical performance of flexible magnetic tape containing chromium dioxide *by R. Bradshaw, B. Bhushan, C. Kalthoff, and M. Warne, p. 203.* The development of a magnetic-recording tape using chromium dioxide suitable for use with the tape drive of the IBM 3480 Magnetic Tape Subsystem was found to require careful optimization of the chemical and mechanical properties of the coating. This paper discusses the role of chromium dioxide in the oxidative and hydrolytic degradation of the polyester-polyurethane binders used in most flexible tape coatings, and the subsequent necessity for careful binder selection to eliminate (for all practical purposes) these degradative effects. In addition to the chemical behavior, the paper discusses the role of the interaction of the chromium dioxide with the binder necessary to obtain mechanical performance suitable for the 3480 tape drive. A high modulus and a relatively high glass-transition temperature were found to be required to avoid changes in the frictional properties of the tape. The incorporation of a rough-textured back coat was found to control the change in the surface topography of the recording surface near the spool hub which arises as a result of compressive forces.

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Key-sequence data sets on indelible storage *by M. C. Easton, p. 230.* Methods for creating and maintaining key-sequence data sets without overwriting the storage medium are described. These methods may be applied to erasable or to write-once storage devices, and they are compatible with conventional device error-management techniques. All past values of data records are preserved in a data structure called a Write-Once B-Tree. Rapid random access is available to records by key value; rapid sequential access is available to records in key-sequence order. Moreover, queries requesting data as of a previous time are processed as rapidly as requests for current data. Access time is proportional to the logarithm of the number of *current* records in the database. Efficient methods for inserting, updating, and deleting records are described. Upper bounds for tree depth and for storage consumption are given and compared with results from simulation. It is concluded that, with rapidly improving storage technologies, indelible databases will become practical for many applications.

The average complexity of depth-first search with backtracking and cutoff *by H. S. Stone and P. Sipala, p. 242.* This paper analyzes two algorithms for depth-first search of binary trees. The first algorithm uses a search strategy that terminates the search when a successful leaf is reached. The algorithm does not use internal cutoff to restrict the search space. If N is the depth of the tree, then the average number of nodes visited by the algorithm is as low as $O(N)$ and as high as $O(2^N)$ depending only on the value of the probability parameter that characterizes the search. The second search algorithm uses backtracking with cutoff. A decision to cut off the search at a node eliminates the entire subtree below that node from further consideration. The surprising result for this algorithm is that the average number of nodes visited grows linearly in the depth of the tree, regardless of the cutoff probability. If the cutoff probability is high, then the search has a high probability of failing without examining much of the tree. If the cutoff probability is low, then the search has a high probability of succeeding on the leftmost path of the tree without performing extensive backtracking. This model sheds light on why some instances of NP-complete problems are solvable in practice with a low average complexity.

On-the-fly decoder for multiple byte errors *by A. M. Patel, p. 259.* Multiple-error-correcting Reed-Solomon or BCH codes in $GF(2^b)$ can be used for correction of multiple burst errors in binary data. However, the relatively long time required for decoding multiple errors has been among the main objections to applying these schemes to high-performance computer products. In this paper, a decoding procedure is developed for on-the-fly correction of multiple symbol (byte) errors in Reed-Solomon or BCH codes. A new decoder architecture expands the concept of Chien search of error locations into computation of error values as well, and creates a synchronous procedure for complete

on-the-fly error correction of multiple byte errors. Forney's expression for error values is further simplified, which results in substantial economies in hardware and decoding time. All division operations are eliminated from the computation of the error-locator equation, and only one division operation is required in the computation of error values. The special cases of fewer errors are processed automatically, using the corresponding smaller set of syndromes through a single set of hardware. The resultant decoder implementation is well suited for LSI chip design with pipelined data flow. The implementation is illustrated with an example.

Design and performance of a magnetic head for a high-density tape drive *by D. M. Cannon, W. R. Dempwolf, J. M. Schmalhorst, F. B. Shelledy, and R. D. Silkensen, p. 270.* The design of a magnetic head for use in the tape drive portion of the IBM 3480 Magnetic Tape Subsystem required that advances be made in track density and linear recording density while meeting requirements for signal quality, manufacturability, and reliability. The design that was developed to fulfill these needs combines ferrite pole-pieces, magnetoresistive read elements, and planar-deposited write turns. This paper describes the read and write elements of the head and the approach used in the selection of the design parameters.

Symmetric stochastic Petri nets *by L. A. Prisgrove and G. S. Shedler, p. 278.* The stochastic Petri net (SPN) model is well suited to formal representation of concurrency, synchronization, and communication. In this paper we focus on discrete event simulation methods for SPN models with special structure and define a symmetric SPN. Exploiting properties of a symmetric SPN and underlying regenerative process structure, we establish steady state estimation procedures based on independent, nonidentically distributed blocks of the marking process. We also establish estimation procedures for passage times in the symmetric SPN setting. These results lead to efficient estimation procedures for delay/throughput characteristics of ring networks with identical ports.

Compiling circular attribute grammars into Prolog *by B. Arbab, p. 294.* This paper describes an algorithm for compiling attribute grammars into Prolog. The attribute grammars may include inherited and synthesized attributes and contain recursive (circular) definitions. The semantics of the recursive definitions is defined in terms of a fixed-point finding function. The generated Prolog code stands in direct relation to its attribute grammar, where logical variables play the role of synthesized or inherited attributes. Thus an effective method for the execution of recursive attribute grammars has been defined and applied.

Least-squares storage-channel identification *by J. M. Cioffi, p. 310.* Pulse (dibit) and step (transition) responses for magnetic-storage channels are important for detection-circuitry design and for comparison of various media, heads, and other channel components. This paper presents a least-squares procedure that can be used to identify the dibit and transition responses from measurements of the read-head response to any known data sequence written on the medium. The method yields significantly higher-quality estimates for the dibit and step shapes than does determining these same characteristics by measuring the average response to isolated transition or by performing a Discrete Fourier Transform (DFT) on the response to a pseudorandom data pattern. The new method can be implemented off line but also can be made sufficiently efficient to be implemented with a microprocessor for use in self-optimizing (adaptive) channel detection circuitry.

A maximum-energy-concentration spectral window *by L. C. Barbosa, p. 321.* A time-discrete solution method is proposed for realization of a spectral window which is ideal from an energy concentration viewpoint. This window is one that concentrates the maximum amount of energy in a specified bandwidth and hence provides optimal spectral resolution.

On yield, fault distributions, and clustering of particles *by C. H. Stapper, p. 326.* Increasing the levels of semiconductor integration to larger chips with more transistors causes the fault and defect distributions of VLSI memory chips to deviate increasingly further from simple random Poisson statistics. The spatial distributions of particles on semiconductor wafers have been analyzed to gain insight into the nature of integrated circuit defect statistics. The analysis was done using grids of squares known as quadrats. It was found that the cluster parameter, which until now has been treated as a constant, did vary with quadrat area. The results also show that the deviation from Poisson statistics continues to increase into the realm of wafer-scale integration or WSI. Computer simulations were used to verify this effect.

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Preface *by P. Chaudhari, p. 354.*

Scanning tunneling microscopy *by G. Binnig and H. Rohrer, p. 355.* Presented here is an overview of the present status and future prospects of scanning tunneling microscopy. Topics covered include the physical basis of the scanning tunneling microscope, its instrumentation aspects, and its use for structural and spectroscopic imaging—on a scale which extends to atomic dimensions. Associated experimental and theoretical studies are reviewed, including several which suggest potential applicability of this new type of microscope to a relatively broad range of biological, chemical, and technological areas.

Squeezable tunneling junctions *by P. K. Hansma, p. 370.* Squeezable tunneling junctions establish the current state of the art for resistance stability of mechanically adjustable tunneling structures at $\Delta R/R \approx 0.1\%$. This is sufficient for use

in connection with spectroscopies as subtle as phonon spectroscopy, but it is marginal and cannot at present be maintained to high enough bias voltage to permit molecular vibrational spectroscopy. Squeezable junctions have been used for characterizing bulk samples and for differential capacitance-voltage analyses of semiconductors.

Electronic structure and tunneling current for chemisorbed atoms *by N. D. Lang, p. 374.* We discuss the tunneling current density in the vacuum region between two planar metal electrodes, one of which has an atom chemisorbed on its surface. The relation of this current distribution to the electronic structure of the adatom is analyzed. The study of this model problem leads to a better understanding of important aspects of the current flow in the scanning tunneling microscope. The emphasis of this work is not so much on the question of resolution discussed in other theoretical studies as on the characteristic signatures of chemically different atoms.

Application to biology and technology of the scanning tunneling microscope operated in air at ambient pressure *by A. M. Baró, R. Miranda, and J. L. Carrascosa, p. 380.* We have investigated the operation of the scanning tunneling microscope (STM) in air at atmospheric pressure, thus permitting the imaging of samples without the need for subjecting them to a vacuum environment. Clearly, this may be of practical importance for many types of samples having biological and technological interest. Imaging of biological samples has been found to be possible after deposition onto a flat structureless conducting substrate (highly oriented pyrolytic graphite). Three-dimensional profiles of structures derived from the virus designated as bacteriophage $\phi 29$ could thus be obtained. Other profiles have been obtained which indicate applicability to surfaces of technological interest: for example, in the measurement of the surface roughness of industrial components with increased precision, suggesting use of the STM as a new standard instrument for that purpose.

Tunneling microscopy from 300 to 4.2 K *by S. A. Elrod, A. Bryant, A. L. de Lozanne, S. Park, D. Smith, and C. F. Quate, p. 387.* A scanning tunneling microscope (STM) has been developed for operation over the full temperature range from 300 to 4.2K. At room temperature, the instrument has been used to produce topographic images of grain structure in a copper-titanium alloy foil and of atomic structure on a Pt(100) surface. At low temperatures, the instrument can be used in a new spectroscopic mode, one which combines the high spatial resolution of the STM with the existing technique of electron tunneling spectroscopy. This new capability has been demonstrated by using the microscope to probe spatial variations in the superconducting character of a niobium-tin alloy film.

A scanning tunneling microscope for surface science studies *by J. E. Demuth, R. J. Hamers, R. M. Tromp, and M. E. Welland, p. 396.* A new design is described for a scanning tunneling microscope intended for surface science studies. The performance of the microscope is evaluated from tunneling images obtained of the Si(111) 7×7 surface. Periodic structures, point defects, and grain boundary structures are observed with atomic-scale resolution and are discussed. Illustrations of various types of image processing and data display are presented.

Defects on the Pt(100) surface and their influence on surface reactions—A scanning tunneling microscopy study *by W. Hösler, R. J. Behm, and E. Ritter, p. 403.* Structural differences between a clean, reconstructed Pt(100) surface and one exhibiting chemical or structural irregularities have been identified by means of a scanning tunneling microscope. The (temperature-dependent) defect structure of a surface which had undergone a phase transition involving mass transport was characterized and compared to results obtained using other techniques. The catalytic activity of surface step sites was probed by the thermal decomposition of ethylene. The resulting surface roughening and buildup of carbon, which could be resolved in STM images, clearly showed that the decomposition proceeds from terrace edges.

Spectroscopy of electronic states of metals with a scanning tunneling microscope *by W. J. Kaiser and R. C. Jaklevic, p. 411.* We have constructed a scanning tunneling microscope (STM) and have obtained current-voltage derivative spectra from metal surfaces. For Au(111) we have observed an electronic surface state 0.4 eV below the Fermi energy. This state has previously been observed with photoemission and oxide tunneling experiments. We have also observed strong peaks in spectra obtained from Pd(111) which we identify with surface states and effects derived from bulk energy bands. In the voltage range investigated here, tunneling takes place through the entire vacuum gap between the metallic tip of the microscope and the surface of the sample being examined. The STM spectroscopy results reported here are compared with previous experimental work and theory. These intrinsic surface states are the first which have been observed with the STM and demonstrate its unique applicability to the investigation of surface electronic structure.

Some design criteria in scanning tunneling microscopy *by D. W. Pohl, p. 417.* Optimum functioning of a scanning tunneling microscope (STM) requires tip-to-sample position control with picometer precision, a rough and fine positioning capability in three dimensions, a scanning range of at least 100 times the lateral resolution, a scanning speed as high as possible, and also, preferably, simplicity of operation. These requirements have to be satisfied in the presence of building vibrations with up to micrometer-size amplitudes, temperature drift, and other perturbations. They result in design rules, presented and discussed here, for the optimization of damping, stiffness, electrical control circuitry, and the performance of the piezoelectric actuators usually employed in STMs.

Possible mechanisms of atom transfer in scanning tunneling microscopy *by R. Gomer, p. 428.* Various mechanisms for the sudden transfer of an atom from or to the tip of a scanning tunneling microscope are considered. It is concluded that thermal desorption could be responsible and also that quasi-contact in which the adsorbed atom is in effect "touching" both surfaces, which would still be separated from each other by 2–4 Å, can lead to unactivated transfer via tunneling. For barrier widths as small as 0.5 Å, however, tunneling becomes negligible.

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Wide-range, low-operating-voltage, bimorph STM: Application as potentiometer *by P. Muralt, D. W. Pohl, and W. Denk, p. 443.* An STM is described which operates at voltages ≤120 V. Its 3D scanner offers a wide range of displacements, has low drift and hysteresis, and exhibits good resolution. These features make it interesting for technical applications. In addition, its use as a potentiometer is described.

Traversal time for tunneling *by M. Büttiker and R. Landauer, p. 451.* Tunneling of carriers through a barrier is characterized not only by a transmission and reflection probability, but also by the time it takes a carrier to traverse the barrier. Recent work which discusses the traversal time is summarized, and its relevance is highlighted by discussing several tunneling phenomena.

Properties of vacuum tunneling currents: Anomalous barrier heights *by J. H. Coombs and J. B. Pethica, p. 455.* A design of STM which does not use vacuum internal vibration isolation and may be cooled to liquid helium temperatures is described. Tunneling current characteristics underlying STM operations are discussed. A model is presented to explain the anomalously low (<1 eV) tunneling barrier heights often observed. On the basis of this model we suggest criteria for obtaining reliable STM images.

Mono-atomic tips for scanning tunneling microscopy *by H.-W. Fink, p. 460.* By field-ion microscopy techniques, we have been able to create stable tips whose very ends are made up of just one individual atom, deposited from the gas phase onto an upper terrace of a pyramidal (111)-oriented tungsten tip. The first three layers of the tip consist of one, three, and seven atoms, respectively. Consequences of these observations for the understanding of energy transfer between gas-phase atoms and a solid surface are also discussed.

Scanning tunneling microscopy of cleaved semiconductor surfaces *by R. M. Feenstra and A. P. Fein, p. 466.* Scanning tunneling microscopy is used to study the surface topography of cleaved GaAs(110) and Si(111) surfaces. For GaAs we observe 1×1 periodicity, with an [001] corrugation amplitude of typically 0.2 Å and a [110] corrugation amplitude of ~ 0.05 Å. Surface point defects are observed, consisting typically of ~ 0.7-Å-deep depressions extending along the rows. For Si(111), we find a periodicity of two unit cells, indicating the presence of the 2×1 reconstruction. We observe a maximum [211] corrugation amplitude of 0.5 Å and a [011] corrugation amplitude of < 0.02 Å, consistent with the π-bonded chain model for this surface. Structural disorder on the surface most commonly appears as "protrusions" along or crossing over between the chains. Orientational disorder is observed in the tilt of the chains.

Scanning tunneling microscopy of surface microstructure on rough surfaces *by J. K. Gimzewski and A. Humbert, p. 472.* An important feature of the scanning tunneling microscope (STM) is its ability to image nonperiodic or disordered surfaces with atomic or near-atomic lateral and vertical resolution. Many physical and chemical properties of surfaces and interfaces are sensitive to, and in some cases determined by, random roughness or surface disorder, although our understanding is hampered by the lack of suitable techniques for investigating atomic-scale features. We present STM results for microcrystalline Ag and nanocrystalline silicon surfaces which demonstrate the unique topographic data obtainable using the STM. For comparison, the STM studies are complemented by data obtained using conventional techniques. Furthermore, the ability of the STM to investigate the influence of growth conditions on surface morphology, such as ion bombardment, adsorption, and condensation temperature, is discussed.

Near-field optical scanning microscopy with tunnel-distance regulation *by U. Dürig, D. Pohl, and F. Rohner, p. 478.* Unprecedented optical image resolution (20 nm to 30 nm) has been obtained with a near-field optical scanner using light with a wavelength of half a micrometer. The key element is an extremely small aperture (~ 10 nm) placed at the very top of a pyramidal screen. The aperture is scanned in the immediate proximity of the surface to be investigated, using vacuum tunneling to sense the distance. The amount of light transmitted by both the aperture and the sample depends sensitively on the optical properties of the sample in the immediate vicinity of the aperture.

Chemical applications of scanning tunneling microscopy *by P. West, J. Kramar, D. V. Baxter, R. J. Cave, and J. D. Baldeschwieler, p. 484.* The development of a scanning tunneling microscope at the California Institute of Technology is well under way. Electron tunneling has been demonstrated, and preliminary surface images of gold films have been obtained. Additional instrumental development is required to achieve the atomic resolution which is required for the study of chemical processes on surfaces. A theoretical model is also being developed for the study of tunneling of electrons from the probe to surfaces with molecular species adsorbed, and with atomic and molecular species intervening between the probe and the surface. These experimental tools and theoretical models, which are being developed concurrently, will be applied to the study of chemical systems and processes

on surfaces. Some of the first molecular species for study will include benzene and pyridine on metal surfaces, and porphyrins and phthalocyanines on pyrolytic graphite. The applications that can be imagined for STM in surface chemistry are very broad, and the choice of additional systems for study will be based on the results of these initial experiments.

Surface modification with the scanning tunneling microscope *by D. W. Abraham, H. J. Mamin, E. Ganz, and J. Clarke, p. 492.* We describe the design and operation of a scanning tunneling microscope (STM) intended for studying surfaces. We are able to prepare samples with ion bombardment and heating, and to characterize them with LEED and Auger analysis *in situ* before scanning with the STM. Data acquisition and analysis are computer-controlled, with a wide variety of options for presentation. In the near future, we will be able to load-lock samples without venting the UHV chamber. Our STM has very low thermal drift, typically of the order of 1 Å/min. In addition to topographical measurements of the surface, we have obtained spatially resolved maps related to the height of the tunnel barrier. We have investigated the effects of scratching the surface with the tip, and have also succeeded in depositing material from the tip onto the surface. Surface diffusion of material is found to play an important role in both of these processes.

STM activity at the University of Basel *by M. Ringger, B. W. Corb, H.-R. Hidber, R. Schlögl, R. Wiesendanger, A. Stemmer, L. Rosenthaler, A. J. Brunner, P. C. Oelhafen, and H.-J. Güntherodt, p. 500.* We have built a scanning tunneling microscope (STM) with a design similar to that published by Binnig and Rohrer. An electromagnetic device called the "maggot" has been developed for nanometer-scale movement over a wide temperature range. So far we have studied the surface topography of a Pd(100) single crystal, of a glassy $Pd_{81}Si_{19}$ alloy, and of graphite. Finally, nanometer-scale structures have been produced with the STM, indicating its potential for high-resolution microfabrication.

Applications of a high-stability scanning tunneling microscope *by H. van Kempen and G. F. A. van de Walle, p. 509.* We have constructed a scanning tunneling microscope which is quite insensitive to vibrations and has a low thermal drift. Low thermal drift is obtained by using a compensating structure for the *z*-axis (perpendicular to the sample surface) of the scan unit and by utilizing symmetry in the *x*- and *y*-directions. To get a low sensitivity to vibrations, we made the scanning unit compact and rigid. A very light tip holder construction allows a high scan speed. We studied different surfaces of Ag single crystals and compared the results with a study of the same surfaces from the inside by a method based on the use of focused conduction electrons. A terrace surface model, introduced to explain the focusing results, has been confirmed for the Ag(001) surface. A description of tip preparation and tip shape is given.

Construction of a UHV scanning tunneling microscope *by S. Chiang and R. J. Wilson, p. 515.* In our laboratory, we have built an ultrahigh-vacuum scanning tunneling microscope (STM). The STM is mounted onto one flange in an ultrahigh-vacuum chamber which is connected by a transfer chamber to a surface-analysis system equipped with 500-Å-resolution SAM/SEM, XPS, LEED, and sample-heating and sample-cleaning facilities. Samples and tips can be moved throughout the combined vacuum system. We describe the design and performance of the instrument and show some preliminary data on Si(111). We also show some recent results of experiments on tip preparation.

A scanning tunneling microscope for the investigation of the growth of metal films on semiconductor surfaces *by T. Berghaus, H. Neddermeyer, and S. Tosch, p. 520.* We describe a scanning tunneling microscope which is part of an apparatus designed for the investigation of metal-semiconductor surfaces. The main parts of the tunneling unit are the piezoelectric walker ("louse") carrying the sample for the coarse approach and a piezoelectric *xyz* system for movement of the tip. The *xyz* system is self-compensating with regard to uniform thermal expansion. Our first measurements have been obtained on a Au(110) surface. The spatial resolution allows the observation of monoatomic steps. Corrugation perpendicular to the rows and troughs of the (110) surface with an amplitude around 1 Å is also visible. The noise in the *z* direction under optimum conditions is smaller than 0.2 Å rms.

Scanning tunneling microscope automation *by M. Aguilar, P. J. Pascual, and A. Santisteban, p. 525.* A computerized system for scanning tunneling microscope control, data acquisition, and display is presented. It is based on the IBM Personal Computer Model XT or AT. An IBM Data Acquisition and Control Adapter card is used for the PC to control the electronic equipment and to measure the voltages applied to the three STM piezoelectric elements and the tunneling current. An IBM Professional Graphics Controller card is used for real-time display of the STM "images." The software has been designed in a modular way to allow the replacement of these cards and other improvements to the equipment. A discussion of performance (scanning speed and size of images) is included. Some image analysis and display tools are included for *a posteriori* image processing.

Theory of scanning tunneling microscopy and spectroscopy: Resolution, image and field states, and thin oxide layers *by N. Garcia, p. 533.* Theoretical studies on the scanning tunneling microscope and its spectroscopic version are reviewed. This research has shown that the conductance of the tunneling electrons is strongly influenced by the classical image potential. The introduction of this potential increases the conductance, although the slope of the logarithm of the conductance versus electrode separation remains practically constant. The image force also has focusing effects on the tunneling electrons and produces a minimum in the

resolution for ~ 5 Å electrode separation. Spectroscopic levels have been calculated for the image states held by the tunneling potential. The results of this work agree very well with experimental data and indicate that the evolution of the observed tunneling spectroscopic levels with applied field is very sensitive to the image potential, and, moreover, that the whole series of image states can be obtained by extrapolation to zero applied field. Work is also presented on the theoretical aspects of tunneling spectroscopy of thin oxide layers grown on a metal substrate—NiO on Ni(100). From theory and experimental data, information can be obtained about the electronic band structure and the number of layers of the oxide. All results of the above research are in accord with the experimental data of Binnig, Rohrer, et al.

Computer automation for scanning tunneling microscopy *by P. H. Schroer and J. Becker, p. 543.* Computer automation has become a necessary part of the scanning tunneling microscope (STM). We have designed a comprehensive data acquisition and image processing IBM PC/AT workstation to complement the STM. The computer is used to control the raster scans, to acquire multichannel analog data, and to store the data for later analysis both at the workstation and on a host computer. New features include the use of PC/AT extended memory, large backup storage, and image processing at the workstation. Real-time gray-scale imaging provides quick and comprehensive information to scientists and engineers. The system is flexible enough to interface with many microscope designs and with other laboratory automation projects. A mainframe host computer system is loosely coupled with the workstation to provide off-line processing, hard copy, and mass storage.

The behavior and calibration of some piezoelectric ceramics used in the STM *by S. Vieira, p. 553.* The high resolution and displacement measurement in the scanning tunneling microscope are dependent upon the behavior of the piezoelectric ceramics used for moving the tip. In this paper certain characteristics and features of piezoelectric ceramics relevant to the desired precision are discussed. These characteristics are the relaxation aftereffects that follow the change of the applied electric field, and the temperature dependence of the piezoelectric response. The above effects have been analyzed in four commercial piezoelectric ceramics by the three-terminal capacitance measurement technique.

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Microtasking on IBM multiprocessors *by P. Carnevali, P. Sguazzero, and V. Zecca, p. 574.* The demand for very high computing performance has become increasingly common in many scientific and engineering environments. In addition to vector processing, parallel computing is now considered a useful way to enhance performance. However, parallel computing tends to be unpopular among users because, with presently available technology and software, it requires explicit programmer intervention to exploit architectural parallelism. This intervention can be minor in some cases, but it often requires a nonnegligible amount of program restructuring, or even a reformulation of some of the algorithms used. In addition, it makes program debugging considerably more difficult. Tools for interprocedural program analysis, able to analyze at high levels large FORTRAN programs composed of many subroutines and to perform an automatic high-level parallel decomposition, are being developed at IBM. As an additional possibility, low-level parallelism could also be exploited automatically. This would greatly simplify the program analysis needed in a compiler in order to automatically insert parallel constructs in a program. However, this could only be efficient in an environment in which the cost for scheduling and synchronizing parallel activities is extremely small. Such a "microtasking" environment has been realized, at a prototype level, for IBM multiprocessors and is described in this paper. Its applicability and potential are illustrated with the help of some simple examples. These examples show that, with microtasking, good processor utilization and useful speed-ups are achieved even for fine-grain problems. The user interface of the prototype is described, both at the FORTRAN and at the Assembler level, and the possibility of incorporating this environment into a FORTRAN compiler is discussed.

Compiling APL: The Yorktown APL Translator *by G. C. Driscoll, Jr. and D. L. Orth, p. 583.* The Yorktown APL Translator (YAT) permits functions written in APL to be compiled using an existing compiler for part of the process. It also creates tables that allow the APL2 Release 2 interpreter to call the compiled code. The code can also be called from a Fortran main routine. This paper outlines the history of APL compilation, the motivation for producing YAT, the design choices that were made, and the manner of implementation. Sample APL functions and their translations are shown, and the time required to interpret these functions is compared with the time required to execute the compiled code. Possible further work is discussed.

Program analysis and code generation in an APL/370 compiler *by W.-M. Ching, p. 594.* We have implemented an APL/370 compiler which accepts a subset of APL that includes most language features and a majority of APL primitive functions. It produces System/370 assembly code directly to be run independently of an interpreter. The compiler does not require variable declarations. Its front end, which is machine-independent, employs extensive type-shape analysis based on a type-shape calculus of the primitive functions and global dataflow analysis. Its back end does storage mapping, code generation for various primitive functions, and register management. For one-line functions, compiled code executes at 2–10 times the speed of the interpreter. On programs with many iterations, the execution time of the compiled code not only is dramatically better than that of interpretation, but is actually fairly close to that of FORTRAN. This removes the performance penalty of APL in computation-intensive applications.

An automatic overlay generator *by R. Cytron and P. G. Loewner, p. 603.* We present an algorithm for automatically generating an overlay structure for a program, with the goal of reducing the primary storage requirements of that program. Subject to the constraints of intermodule dependences, the algorithm can either find a maximal overlay structure or find an overlay structure that, where possible, restricts the program to a specified amount of primary storage. Results are presented from applying this algorithm to three substantial programs.

An execution architecture for FP *by T. Huynh, B. Hailpern, and L. W. Hoevel, p. 609.* FP is a functional programming language proposed by John Backus to liberate programming from the "von Neumann Style." We define here an architecture (FP machine model) that is intended to allow easy and efficient implementation of FP on a conventional von Neumann machine. We present a new execution architecture for FP based on Johnston's contour model and on Hoevel and Flynn's notion of DEL/DCA architectures. We call our architecture DELfp, a Directly Executed Language for FP.

Early error detection in syntax-driven parsers *by A. V. Moura, p. 617.* The early error detection capabilities of syntax-driven parsers are studied. The classes of weak precedence and simple mixed-strategy precedence parsers are chosen as the object of study. Very similar techniques could be used to obtain related results for other classes of syntax-driven parsers. We investigate whether the correct-prefix and the viable-prefix properties can be enforced within these classes: A negative result is obtained for the first class and a positive one for the second. Moreover, for the simple mixed-strategy class the relationship between early error detection and parser size is studied. Some lower bounds on the parser size are proven for simple mixed-strategy precedence parsers that have the viable-prefix property.

A computerized autoradiographic technique for the simultaneous high-resolution mapping of myocardial blood flow and metabolism *by A. L'Abbate, C. Paoli, R. Porinelli, and M. G. Trivella, p. 627.* By using both radioactive particulate and diffusible tracers, combined with computerized processing and analysis of generated autoradiographs, a new technique for the high-resolution mapping of organ blood flow and metabolism has been developed. In this paper the technique has been evaluated for the myocardium.

Mechanical design of the cartridge and transport for the IBM 3480 Magnetic Tape Subsystem *by D. J. Winarski, W. W.-C. Chow, J. G. Bullock, F. B. Froehlich, and T. G. Osterday, p. 635.* The IBM 3480 Magnetic Tape Subsystem has achieved significant improvements over its predecessor, the 3420, in speed, data density, and floor-space requirements. The 3-megabyte-per-second data rate of the 3480, which is 2.4 times that of the 3420, was accomplished through the use of chromium-dioxide tape stored in a compact, single-reel cartridge threaded to a take-up reel. A sixfold increase in data density over the 3420 allowed reduction of the size of the 3480 reel, which was essential for rapid acceleration of the tape in the 3480's reel-to-reel transport. The increased data density also demanded substantial improvements in tape guiding and tape-motion control. This paper describes how mechanical analysis and design contributed to the achievement of these advances and aided in overcoming the ensuing problems.

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Digital halftoning on the IBM 4250 Printer *by G. Goertzel and G. R. Thompson, p. 2.* A method of reproducing high-quality continuous-tone images via the IBM 4250 Printer is presented. The approach is modeled on the halftone process used in conventional lithography but is adapted to discrete bilevel printing and digital processing. We use a combination of standard and novel techniques. These include generation and calibration of a set of halftone dot patterns, randomized error propagation in pattern selection, and resolution enhancement in areas of high intensity gradients. The resultant images have good gray-scale rendition and sharp edges without the problems of contouring and worminess often associated with digital image reproduction. We have named this approach PREPRESS: Picture Rendition using Error Propagation and Resolution Enhancement in Simulated Screening.

Binary-image-manipulation algorithms in the Image View Facility *by K. L. Anderson, F. C. Mintzer, G. Goertzel, J. L. Mitchell, K. S. Pennington, and W. B. Pennebaker, p. 16.* Most current implementations of electronic mail deal primarily with coded information. A scanned-document-handling system that could scan a document, distribute it, display it on terminals, and print it on host-attached printers would offer a similar convenience for documents in hard-copy rather than coded form. For such a system to be practical, fast software is needed for a number of image-manipulation functions. The required functions are compression, to reduce the size of the data files; decompression, to reconstruct the scanned document; scaling, to match the resolution of the scan to the resolution of the display or printer; and rotation, to reorient documents scanned sideways or upside down. This paper describes a collection of algorithms underlying fast software for manipulating binary images that is used in the Image View Facility, a System/370-based software package that permits the display and printing of binary images at various resolutions.

PANDA: Processing Algorithm for Noncoded Document Acquisition *by Y.-H. Chen, F. C. Mintzer, and K. S. Pennington, p. 32.* With a scanned-document-handling system, documents can be scanned, stored, transmitted to remote locations, viewed on displays and terminals, edited, and printed. These systems hold much promise for office automation, since they facilitate the communication and storage of information that is not easily recoded into the traditional formats for text and graphics. However, most of the current systems that perform these functions are intended for documents that at every point are either black or white, but not gray. These systems effectively exclude documents that contain regions with varying shades of gray (known as continuous-tone regions). PANDA, the Processing Algorithm for Noncoded Document Acquisition, is a technique that processes *mixed documents,* those that contain continuous-tone regions in addition to text, graphics, and line art. PANDA produces a high-quality binary representation of all regions of a mixed document. Furthermore, all regions of the binary representation, including the continuous-tone image regions, are significantly compressed by the run-length-based compression algorithms that underlie scanned-document-handling systems. This is a key feature of PANDA. Indeed, this compression makes practical the inclusion of mixed documents into many existing systems.

YODA: An advanced display for personal computers *by S. Gupta, D. F. Bantz, P. N. Sholtz, C. J. Evangelisti, and W. R. DeOrazio, p. 44.* YODA (the YOrktown Display Adapter) is an experimental display designed to improve the quality and speed of users' interactions with personal computers. This paper describes the YODA hardware architecture and software design. Special attention is given to techniques used for antialiasing. The various trade-offs and decisions that were made are discussed.

Document convergence in an interactive formatting system *by D. D. Chamberlin, p. 58.* One of the most complex aspects of document formatting is the processing of references to remote objects such as headings and figures. In the case of a forward reference to an object that occurs later in the document, two formatting passes are usually needed before the document converges to a stable state. Some documents require more than two passes to converge, and cases are known of documents that never converge but oscillate between two unstable states. This paper describes the techniques used for resolving references and detecting document convergence by the Interactive Composition and Editing Facility, Version 2 (ICEF2). ICEF2 is an interactive formatting system that allows users to move about in a document, editing and reformatting pages. The concepts of *formatting pass* and *document convergence* are discussed in the context of interactive formatting. A description is given of the ICEF2 data store, a small relational database manager with special features for detecting document convergence. A sample ICEF2 style definition is discussed to illustrate how ICEF2 deals with document elements whose appearance depends on their location on the page.

LEXX—A programmable structured editor *by M. F. Cowlishaw, p. 73.* Many sophisticated and specialized editing programs have been developed in recent years. These editors help people manipulate data, but the diversity complicates rather than simplifies computer use. LEXX is an editing program that can work with the syntax and structure of the data it is presenting, yet is not restricted to just one kind of data. It is used for editing programs, documents, and other material and hence provides a consistent environment for the user regardless of the editing task. The new *live parsing* technique used by LEXX means that it can be programmed to handle a very wide variety of structured data. The structure information is, in turn, used to improve the presentation of data (through color, fonts, and formatting), which makes it easier for people to deal with the text being edited.

A method for efficient storage and rapid application of context-sensitive phonological rules for automatic speech recognition *by R. L. Mercer and P. S. Cohen, p. 81.* In an automatic speech-recognition system, the application of phonological rules to phonemic strings in order to create phonetic graphs is a computationally time- and storage-consuming process. A great many such graphs must be constructed during the decoding phase; thus it is important to be able to rapidly construct phonetic graphs for strings of words from graphs of individual words. However, because many phonological rules operate across word boundaries or require interword context, it is not possible to determine a unique, context-independent phonetic graph for a word. We describe a method for determining the phonetic graph for a word in isolation, together with auxiliary information to allow phonetic graphs for different words to be rapidly interconnected to form a phonetic graph for a string of words; the method also reduces storage requirements significantly.

Feature analysis for symbol recognition by elastic matching *by J. M. Kurtzberg, p. 91.* A technique has been developed for the recognition of unconstrained handwritten discrete symbols based on elastic matching against a set of prototypes generated by individual writers. The incorporation of feature analysis with elastic matching to eliminate unlikely prototypes is presented in this paper and is shown to greatly reduce the required processing time without any deterioration in recognition performance.

Drop formation by DOD ink-jet nozzles: A comparison of experiment and numerical simulation *by T. W. Shield, D. B. Bogy, and F. E. Talke, p. 96.* This paper presents a comparison of a numerical simulation of drop formation and ejection from a drop-on-demand (DOD) ink-jet nozzle with experimental observations from a particular nozzle-transducer design. In the numerical simulation, first the pressure waves in the transducer chamber are calculated using inviscid compressible flow theory to obtain the pressure history at the inner face of the nozzle plate. Then a viscous momentum integral computation is applied to the nozzle to obtain the velocity history at the outer face of the nozzle plate. Finally, the free surface shape is calculated using finite-difference methods on the one-dimensional equations for an inviscid incompressible free jet with surface tension that uses the nozzle exit velocity history as the driving boundary condition. The computations are compared with drop formation photographs obtained from a particular nozzle-transducer design. Encouraging agreement is obtained, but the numerical model will require added sophistication before detailed agreement can be expected.

DNA vectorgrams: Representation of cancer genes as movements on a 2D cellular lattice *by C. A. Pickover, p. 111.* A brief introduction introduction to a computer graphics characterization of cancer DNA sequences, as well as other biologically interesting sequences, is presented. The procedure described takes DNA sequences containing n bases and computes n two-dimensional real vectors. When displayed on a planar unit-cellular lattice, these characteristic patterns appear as a "DNA vectorgram," $C(n)$. Several demonstration plots are provided which indicate that $C(n)$ is sensitive to certain statistical properties of the sequence of bases and allows the human observer to visually detect some important sequence structural properties and patterns not easily captured by traditional methods. The system presented has as its primary focus the fast characterization of the progression of sequence data using an interactive graphics system with several controlling parameters.

Path hierarchies in interconnection networks *by P. A. Franaszek, p. 120.* This paper treats the problem of latency minimization in an interconnection network for a system of N high-performance devices. The networks considered here have data transport separated from control, with the data subnetwork designed so that each network function requires only a single control message, and thus only one contention-resolution delay. For sufficiently large N it is shown that (for an abstract hardware model) minimizing contention delays requires that each message subject to such delays have more than one way of reaching its destination (e.g., via a path hierarchy). The overall approach is discussed in the context of the processor-memory interconnection problem in parallel computing.

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Preface *by S. Winograd, p. 150.*

Science in industry *by R. E. Gomory, p. 151.* The industrial environment contains problems of practical importance. To exploit that environment, an industrial research group must accept the responsibility for forming strong and useful relationships with the rest of the company of which it is a part. Opportunities for contributing to both the industrial and academic worlds stem from the many product-related problems for which existing science offers no solution, but which suggest new scientific directions.

Reflections on the early days of the department *by H. H. Goldstine, p. 154.* The paper contains the reminiscences of the founding director of the Mathematical Sciences Department in IBM Research. It is interspersed with a number of anecdotes about his friend and colleague, John von Neumann. It attempts in a short space to recapitulate the history of a distinguished department of mathematics in an industrial environment in an informal and hopefully humorous manner.

Applied mathematics, a national view *by H. Cohen, p. 158.* The development of applied mathematics in the United States during the past forty years is described, including the role of computers and computation in enlarging and changing the field. The growth of the profession is also discussed, along with needs for training and funding for the future.

A view of Approximation Theory *by T. J. Rivlin, p. 162.* This is a selective survey of Approximation Theory which touches on the concepts of best approximation, good approximation, approximation of classes of functions, approximation of functionals, and optimal estimation.

Numerical analysis and the scientific method *by J. Glimm and D. H. Sharp, p. 169.* The computer has given rise to a new mode of scientific practice, and today computational science stands beside theory and experiment as a fundamental methodology. The impact of the computer revolution on science can be projected from current trends. The demands to be made on computing methodologies will be reviewed. One of the demands is an ongoing need for excellence in computational methodologies. Generic difficulties encountered in meeting these challenges will be discussed. Recent work of the authors and others will be reviewed in this context.

Some stability techniques for multistep methods *by F. Odeh, p. 178.* A partial survey is given of sundry results in the stability theory of multistep formulae when these are used to integrate time-varying or nonlinear stiff systems, with emphasis on systems arising in circuit analysis.

Factoring logic functions *by R. K. Brayton, p. 187.* A factored form is a representation of a logic function that is either a single literal or a sum or product of factored forms. Thus it is equivalent to a parenthesized algebraic expression. It is one of many possible representations of a logic function, but seems to be the most appropriate one for use in multilevel logic synthesis. We give a number of methods for obtaining different factored forms for a given logic function. These methods range from purely algebraic ones, which are quite fast, to so-called Boolean ones, which are slower but are capable of giving better results. One of the methods given is both fast and gives good results, and is useful in providing continuous estimates of area and delay as logic synthesis proceeds. In multilevel logic synthesis, each of the methods given has a use in a system where run-time and quality are traded off. We also formulate the problem of optimal algebraic factorization, and pose its solution as a rectangle-covering problem for which a heuristic method is given.

Some aspects of the theory of statistical control schemes *by E. Yashchin, p. 199.* Control schemes (charts) are widely used in industrial quality control as means of monitoring the quality of manufactured products. These schemes provide a set of criteria for testing whether a given sequence of observations corresponds to an "on-target" state of the production process. In the present work, we consider some graphical, computational, and statistical aspects of control charting—criteria of performance, methods of derivation, analysis, design, etc. We introduce the class of "Markov-type" control schemes and discuss some of its properties.

The group problem and integer programming duality *by E. L. Johnson, p. 206.* Some duality results for integer programming based on subadditive functions are presented first for linear programs and then for the group problem. A similar result for the knapsack problem is given and then a relationship between facets for the group relaxation and facets of the knapsack problem is given. The mixed integer cyclic group problem is then considered and a dual problem given. A common theme is to try to characterize the strongest possible dual problem or equivalently the smallest possible cone of subadditive functions.

Fourier transforms that respect crystallographic symmetries *by L. Auslander and M. Shenefelt, p. 213.* In crystallography one has to compute finite Fourier transforms that are often very large and often respect crystallographic symmetries. In this paper we discuss efficient finite Fourier transform algorithms on $5 \times 5 \times 5$ points that respect a collection of crystallographic symmetries. Although the size is too small for any practical problems, the methods indicated in this paper can be extended to problems of meaningful size.

The torus and the disk *by R. L. Adler, p. 224.* This paper is a survey of a coherent program of mathematics spanning 28 years. It begins with questions concerning classification and structure in ergodic theory and abstract dynamical systems and describes the author's involvement with toral automorphisms, topological entropy, iteration of maps on the interval, symbolic dynamics, and ultimate engineering applications. It serves as a case study of how unplanned-for practical applications can result from the pursuit of mathematics for its own sake.

The complexity of computations by networks *by N. Pippenger, p. 235.* We survey the current state of knowledge concerning the computation of Boolean functions by networks, with particular emphasis on the addition and multiplication of binary numbers.

Cryptography *by D. Coppersmith, p. 244.* This paper is concerned with two aspects of cryptography in which the author has been working. One is the Data Encryption Standard (DES), developed at IBM and now in wide use for commercial cryptographic applications. This is a "private key" system; the communicants share a secret key, and the eavesdropper will succeed if he can guess this key among its quadrillions of possibilities. The other is the Diffie-Hellman key exchange protocol, a typical "public key" cryptographic system. Its security is based on the difficulty of taking "discrete logarithms" (reversing the process of exponentiation in a finite field). We describe the system and some analytic attacks against it.

Efficient randomized pattern-matching algorithms *by R. M. Karp and M. O. Rabin, p. 249.* We present randomized algorithms to solve the following string-matching problem and

some of its generalizations: Given a string X of length n (the *pattern*) and a string Y (the *text*), find the first occurrence of X as a consecutive block within Y. The algorithms represent strings of length n by much shorter strings called *fingerprints*, and achieve their efficiency by manipulating fingerprints instead of longer strings. The algorithms require a constant number of storage locations, and essentially run in real time. They are conceptually simple and easy to implement. The method readily generalizes to higher-dimensional pattern-matching problems.

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Preface *by M. A. Wesley, p. 276.*

Solid modeling for production design *by R. N. Wolfe, M. A. Wesley, J. C. Kyle, Jr., F. Gracer, and W. J. Fitzgerald, p. 277.* This paper describes a solid modeling and interactive graphics computer system which is being used for conceptual and detailed design by the mechanical design community at IBM's Data Systems Division Laboratory in Poughkeepsie, New York. The system has evolved from research on solid modeling begun at IBM's Thomas J. Watson Research Center in the mid-70s. Its development has resulted in one of the first major production uses of solid modeling in industry. The system was first tested in pilot and limited production environments in 1981, and is now in production use as the primary design tool for mechanical portions of IBM's large computer mainframes. Its introduction, development, integration, and use are described, and its functional and performance characteristics as well as requirements for future enhancements are discussed. We conclude from our experience that solid modeling has become a significant new production tool for mechanical design.

Piecewise-circular curves for geometric modeling *by J. R. Rossignac and A. A. G. Requicha, p. 296.* Modern solid modelers must be able to represent a wide class of objects, and must support Boolean operations on solids. These operations are very useful for defining solids, detecting interferences, and modeling fabrication processes. Computing the boundaries of solids defined through Boolean operations requires algorithms for surface/surface and curve/surface intersection. Many of the currently available modelers use closed-form parametric expressions for the curves of intersection of quadric surfaces, and compute intersections of these curves with other surfaces by finding the roots of low-degree polynomials. Because the curves that result from intersections involving tori or more complex surfaces generally cannot be expressed in closed form, modelers typically approximate these curves by cubic splines that interpolate points lying on the true intersections. Cubic splines exhibit second-degree continuity, but they are expensive to process in solid modeling computations. In this paper, we trade second-degree continuity for computational simplicity, and present a method for interpolating three-dimensional points and associated unit tangent vectors by smooth space curves composed of straight line segments and circular arcs. These curves are designated as PCCs (for piecewise-circular curves) and have continuous unit tangents. PCCs can be used in efficient algorithms for performing fundamental geometric computations, such as the evaluation of the minimal distance from a point to a curve or the intersection of a curve and a surface. Formulae and algorithms are presented for generating and processing PCCs in solid modelers. We also show that PCCs are useful for incorporating toroidal primitives, as well as sweeping, growing, shrinking, and blending operations in systems that model solids bounded by the natural quadric surfaces—planes, cylinders, cones, and spheres.

Trimmed-surface algorithms for the evaluation and interrogation of solid boundary representations *by R. T. Farouki, p. 314.* Although trimmed surfaces play a fundamental role in the derivation and processing of solid boundary representations, they have received little attention to date. We propose a trimmed-surface formulation appropriate to the Boolean combination of primitives bounded by a family of elementary surface patches (e.g., planes, quadrics, ruled surfaces, surfaces of revolution) with dual parametric rational polynomial and implicit algebraic equations. Partial intersections between pairs of primitive surface patches are formulated precisely as algebraic curves in the parameter space of each patch. These curves are dissected into monotonic branches by the identification of a characteristic point set. The consolidation of all partial intersections yields a system of piecewise-algebraic loops which define a trimming boundary enclosing a parametric domain for the trimmed patch. With few exceptions, the trimmed-surface formulation is based on precisely defined mathematical procedures, in order to achieve maximum robustness. Some basic interrogation algorithms for solids bounded by trimmed-surface elements are also presented, including procedures for ray-tracing, point/solid classification, sectioning, and computation of surface area, volume, center of gravity, moments of inertia, and other mass properties.

Simple unit vectors orthogonal to a given vector *by M. A. O'Connor and G. Gentili, p. 335.* In geometrical computations it is often necessary to find two unit vectors such that they and a given vector form an orthogonal basis. Computationally simple forms for the two unit vectors are clearly useful. We show that they cannot always be chosen to have rational coordinates, but that in general the simplest possible vectors can be chosen to involve only one square root. We develop number-theoretic criteria for the existence of a rational vector and an effective algorithm for calculation of one if it exists. We also discuss storage and time requirements of the algorithm.

Shaping geometric objects by cumulative translational sweeps *by R. C. Evans, G. Koppelman, and V. T. Rajan, p. 343.* This paper introduces the cumulative translational sweep (CTS) as a tool for shaping geometric objects. It describes

how it may be applied, in combination with Boolean operations, to stimulate growth and shrinking over the boundary regions of polyhedral models, and how, by creating additional facets, it may be used to achieve global rounding effects along model edges and around their vertices. CTSs are examined in terms of a conceptual framework that describes their effects as Minkowski sums—of the polyhedra to be swept, with convex polyhedra from the class of mathematical objects known as zonotopes. Included is a discussion of applications in the OYSTER program, a CAD system for the simulation of semiconductor wafer fabrication.

Voronoi diagram for multiply-connected polygonal domains I: Algorithm *by V. Srinivasan and L. R. Nackman, p. 361.* Voronoi diagrams of multiply-connected polygonal domains (polygons with holes) can be of use in computer-aided design. We describe a simple algorithm that computes such Voronoi diagrams in $O(N(\log_2 N + H))$ time, where N is the number of edges and H is the number of holes.

Voronoi diagram for multiply-connected polygonal domains II: Implementation and application *by S. N. Meshkat and C. M. Sakkas, p. 373.* Voronoi diagrams have many novel applications in computer-aided design. In this paper, an implementation of a Voronoi diagram algorithm described in a companion paper by Srinivasan and Nackman is presented. This Voronoi diagram is then used for an application in which equivalent resistance networks are derived from a boundary representation of a two-dimensional VLSI geometry.

An algorithm for automatic identification of R-fields in bond graphs *by S. J. Hood, R. C. Rosenberg, D. H. Withers, and T. Zhou, p. 382.* Bond graphs may be used to model the power flow in dynamic systems. They are especially attractive for modeling systems which function in coupled energy domains, for example, electromechanical systems. For such systems, bond graphs can be used to provide a natural subdivision into power/energy fields: storage, sources, transformers, and dissipation. In the case of nonlinear dissipative fields, implicit, nonlinear, coupled systems of algebraic equations may arise. Causality assignment on the bond graph provides a basis for detecting implicit formulations. This paper presents an algorithm for detection and solution of these forms within a model, thereby providing an opportunity for efficient numerical solution, and includes a brief introduction to bond graphs via an electromechanical system example.

Parallel algorithms for chip placement by simulated annealing *by F. Darema, S. Kirkpatrick, and V. A. Norton, p. 391.* We explore modifications to the standard simulated annealing method for circuit placement which make it more suitable for use on a shared-memory parallel computer. By employing chaotic approaches we allow the parallel algorithms to deviate from the algorithm defined for a serial computer and thus obtain good execution efficiencies for large numbers of processors. The qualitative behavior of the parallel algorithms is comparable to that of the serial algorithm.

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Reducing execution parameters through correspondence in computer architecture *by S. P. Wakefield and M. J. Flynn, p. 420.* The purpose of this study is to develop and extend techniques to provide architectural correspondence between high-level language objects and hardware resources so as to minimize execution time parameters (memory traffic, program size, etc.). A resulting computer instruction set called *Adept* has been emulated, and a compiler has been developed with it as the target language. Although the study was restricted to Pascal, the resulting data are generally applicable to the execution time environment of any procedure-based language. Data indicate that significant bandwidth reductions are possible compared to System/370, VAX, P-code, etc. Specifically, the average improvement ratios realized were instruction bandwidth reduction: 3.46; data read reduction (in bytes): 5.42; data write reduction (in bytes): 14.72.

Performance analysis of the FFT algorithm on a shared-memory parallel architecture *by Z. Cvetanovic, p. 435.* This paper presents a model for the performance prediction of FFT algorithms executed on a shared-memory parallel computer consisting of N processors an the same number of memory modules. The model applies a deterministic analysis to estimate the communication delay through the interconnection network by assuming that all requests arrive at the network in bursts. Our results indicate that the communication delay is significantly affected by the method applied to allocate data to memory modules. For the case in which all data items referenced by a processor during an iteration are allocated to a single memory module, the best-case communication time complexity grows as $O[(\log N)^2/N]$. The worst-case communication time complexity for this case, obtained by a different allocation of data to memory modules, is increased to $O[(\log N)/\sqrt{N}\,]$ due to high network contention. For the case in which the data items referenced by different processors during an iteration are allocated to the same memory module, the communication time complexity is further increased to $O(\log N)$ since all N requests generated by processors are serialized at a single memory module. The methods developed in this paper can be applied for the performance prediction of other well-structured parallel iterative algorithms.

Best and worst mappings for the omega network *by Z. Cvetanovic, p. 452.* This paper presents a study of the best and worst mappings for the omega network proposed by D. H. Lawrie in 1975. We identify mappings that produce no conflicts in the network and mappings that produce a maximum number of conflicts. The analysis of mappings for some typical applications shows that an initial allocation of data to memory modules determines the contention within the

network for all iterations of the algorithm. For the case of the FFT and the bitonic sort algorithm executed on a shared-memory architecture, we prove that if no conflicts are produced during the first iteration of the algorithm, then no conflicts are produced during any other iteration. Moreover, if a maximum number of conflicts are produced during the first iteration, then a maximum number of conflicts are produced during all other iterations of the algorithm. For the d-dimensional grid computations where communication is required with $2d$ nearest neighbors, we prove that if the initial allocation produces no conflicts within the network, then communication with all the neighbors is conflict-free. Also, if the initial allocation produces a maximum number of conflicts, then communication with all the neighbors is maximum-conflict. We show that the omega network cannot produce without conflicts some of the bit-permute mappings such as the perfect shuffle and the bit reversal. The network can produce both of these mappings provided that data items are accessed from memories according to a specific skewed scheme.

Efficient search techniques—An empirical study of the N-Queens Problem *by H. S. Stone and J. M. Stone, p. 464.* This paper investigates the cost of finding the first solution to the N-Queens Problem using various backtrack search strategies. Among the empirical results obtained are the following: 1) To find the first solution to the N-Queens Problem using lexicographic backtracking requires a time that grows exponentially with increasing values of N. 2) For most even values of $N < 30$, search time can be reduced by a factor from 2 to 70 by searching lexicographically for a solution to the $N + 1$-Queens Problem. 3) By reordering the search so that the queen placed next is the queen with the fewest possible moves to make, it is possible to find solutions very quickly for all $N < 97$, improving running time by dozens of orders of magnitude over lexicographic backtrack search. To estimate the improvement, we present an algorithm that is a variant of algorithms of Knuth and Purdom for estimating the size of the unvisited portion of a tree from the statistics of the visited portion.

The inconsistency index method for estimating the accuracy of Schweitzer's approximation *by D. Sitaram, p. 475.* Product-form queueing networks have proved to be useful for predicting the performance of computer systems. In practice, these networks are analyzed using approximate methods because exact methods are computationally too expensive. Schweitzer's approximation is one of the most commonly used. However, there is no method for estimating the error in the solution. This paper proposes a new approach for estimating the error in Schweitzer's approximation for fixed-rate product-form networks. It is based on detecting the extent to which the approximation assumptions used hold. Empirical evidence is presented to show that this approach can be used to accurately predict the error in the approximation.

Exact analysis of round-robin scheduling of services *by H. Takagi, p. 484.* A multi-queue, cyclic-service model with a single-message buffer is considered. Each message consists of a number of characters, and one character is served at the server's each visit. Exact and explicit expressions are derived for performance measures, such as mean cycle time, mean message response time, and mean response time conditioned on the message length. The same model was previously solved by approximation by Wu and Chen [*IBM J. Res. Develop.* 19, No. 5, 486-493 (September 1975)].

Signal degradation through module pins in VLSI packaging *by C.-C. Huang and L. L.-H. Wu, p. 489.* This paper investigates chip-to-chip communication through the modules and board in VLSI packaging. Transmission line models and frequency-dependent transmission line parameters are used in finding the frequency response. The time-domain solution is then obtained through the inverse Fast Fourier Transform. The results show that uncoated module pins, even of relatively short length, can cause severe signal degradation because of their magnetic property. The signal behavior is improved dramatically, however, when the module pins are coated with nonmagnetic conductive material.

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Direct semantics of concurrent languages in the SMoLCS approach *by E. Astesiano and G. Reggio, p. 512.* For years providing syntax-directed methods for the formal definition of concurrent languages has proved to be a challenging task. Problems are even more difficult if a language has some of the typical Ada features, such as strong interference between sequential and concurrent aspects, parameterized semantics, complex data structure, and finally an extremely large size. We have developed an approach, the SMoLCS approach, which extends the denotational method to handle concurrent languages and also provides a solution to the above problems. Indeed, our method has been adopted for the format definition of full Ada within the related EEC project. Here we illustrate the basic principles of the approach, following the so-called direct semantics style used for Ada with the help of a toy language as a running example.

Transaction processing primitives and CSP *by J. C. P. Woodcock, p. 535.* Several primitives for transaction processing systems are developed using the notations of Communicating Sequential Processes. The approach taken is to capture each requirement separately, in the simplest possible context: The specification is then the conjunction of all these requirements. As each is developed as a predicate over traces of the observable events in the system, it is also implemented as a simple communicating process; the implementation of the entire system is then merely the parallel composition of these processes. The laws of CSP are then used to transform the system to achieve the required degree of concurrency, to make it suitable for execution in a multiple-tasking system, for example. Finally, there is a

discussion of how state-based systems may be developed using this approach together with some appropriate notation for specifying and refining data structures and operations upon them and of how the system may be implemented. This work is intended as a case study in the use of CSP.

Specification statements and refinement *by C. Morgan and K. Robinson, p. 546.* We discuss the development of executable programs from state-based specifications written in the language of first-order predicate calculus. Notable examples of such specifications are those written using the techniques Z and VDM; but our interest is in the rigorous derivation of the algorithms from which they deliberately abstract. This is, of course, the role of a *development method.* Here we propose a development method based on *specification statements* with which specifications are embedded in programs—standing in for developments "yet to be done." We show that specification statements allow description, development, and execution to be carried out within a *single* language: programs/specifications become hybrid constructions in which both predicates and directly executable operations can appear. The use of a single language—embracing both high- and low-level constructs—has a very considerable influence on the development style, and it is that influence we discuss: the specification statement is described, its associated calculus of refinement is given, and the use of that calculus is illustrated.

A CCS semantics for NIL *by S. A. Smolka and R. E. Strom, p. 556.* We present a syntax-directed translation of NIL, a high-level language for distributed systems programming, into CCS, Milner's Calculus of Communicating Systems. This translation presents unique problems because of NIL's highly dynamic nature, and makes full use of CCS's descriptive facilities. In particular, we consider NIL constructs for dynamic creation and deletion of processes and communication channels, queued synchronous and asynchronous message passing, nondeterministic message selection, and exception handling. A NIL implementation of a simple command shell is used to illustrate the translation procedure. We discuss various issues and open problems concerning the suitability of CCS as an abstract semantics for NIL.

System Identification: An experimental verification *by R. D. Ciskowski, C. H. Liu, H. H. Ottesen, and S.-U.-Rahman, p. 571.* System identification may be defined as the process of determining a model of a dynamic system using observed system input-output data. The identification of dynamic systems through the use of experimental data is of considerable importance in engineering since it provides information about system parameters which is useful in predicting behavior and evaluating performance. Traditional methods of System Identification are usually time-consuming, costly, and difficult to use in other than a product development environment. Within the last decade, more sophisticated techniques for System Identification have been developed that can simultaneously estimate many parameters accurately and repeatedly. These modern techniques are, in addition, efficient, easy to use, inexpensive, and readily adaptable to manufacturing and in-the-field environments where they can be used to evaluate product quality and performance. This paper describes the use of one such System Identification algorithm to estimate several mechanical parameters of 8-inch hard-disk drive spindles in a manufacturing-like setting. The results obtained are in excellent agreement with results acquired by more conventional methods, and demonstrate the potential benefits of System Identification techniques in evaluating product quality and performance.

Delamination and fracture of thin films *by E. Klokholm, p. 585.* The fracture and delamination of thin films is a relatively common occurrence, and prevention of these mechanical failures is essential for the successful manufacture of thin-film devices. Internal elastic stresses are an inherent part of the thin-film deposition process, and are largely responsible for the mechanical failures of thin films. However, it is not the magnitude of the film stress S which governs film fracture or delamination, but the elastic energy U stored in the film. It is the intent of this presentation to show that the mechanical stability of the film and the substrate requires that U be less than a critical value U_c and that U_c is dependent upon the surface energy γ.

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Contact metallurgy development for VLSI logic *by R. M. Geffken, J. G. Ryan, and G. J. Slusser, p. 608.* The criteria involved with the choice of an ohmic contact material for VLSI logic are discussed. The problems of aluminum penetration encountered with Al metallization and solid-phase epitaxy associated with Al–Si metallization make these interconnect materials incompatible with VLSI technology. The contact resistance characteristics of palladium and platinum silicides were compared to the contact resistance obtained using a titanium contact layer. The contact resistance of palladium silicide increased with extended annealing at 400°C, while the PtSi and Ti contact materials exhibited stable contact resistance under these conditions. A Ti/Al–Cu/Si process which is compatible with a lift-off patterning technique and partial coverage of contacts is described. Rutherford backscattering results indicate that copper and silicon additions to the aluminum metallization retard the Ti–Al reaction. SIMS data show that silicon in Ti/Al–Cu/Si films redistributes during heat treatment, accumulating at the Ti/Al–Cu interface.

Electrical and microstructural investigation of polysilicon emitter contacts for high-performance bipolar VLSI *by J. M. C. Stork, E. Ganin, J. D. Cressler, G. L. Patton, and G. A. Sai-Halasz, p. 617.* Key electrical characteristics of polysilicon emitter contacts in bipolar transistors, such as contact resistance and recombination velocity, are extremely sensitive to the microstructure of the polysilicon/single-crystal

silicon interface. In this study, we correlated the microstructural and electrical characteristics of this interface by performing cross-sectional transmission electron microscopy (XTEM) on *actual* transistors on the same chip where ring-oscillator speeds were measured. The base current and emitter resistance of the fastest devices approached values typical of single-crystal silicon emitters. Interpretation of these electrical data and of the SIMS impurity profile indicates that significant restructuring of the polysilicon/single-crystal interface had taken place. This conclusion was indeed confirmed by the XTEM results. Although the low-current performance was degraded because of higher junction capacitances, the high-current switching speed was improved because of the minimal emitter contact resistance. Since the current gain was sufficiently high and very uniform, it is concluded from this work that minimization of both junction depth and contact resistance is the most important design consideration for high-performance submicron transistors, rather than maximization of the gain enhancement of the polysilicon/single-crystal interface.

Study of contact and shallow junction characteristics in submicron CMOS with self-aligned titanium silicide *by Y. Taur, B. Davari, D. Moy, J. Y.-C. Sun, and C.-Y. Ting, p. 627.* The contact resistance between $TiSi_2$ and shallow n^+/p^+ source-drains in CMOS is studied for a variety of junction depths and silicide thicknesses. The contact contribution to the total device series resistance can be significant if excessive silicon and dopants are consumed during silicide formation. Low contact resistances are obtained for 0.15-μm n^+ and 0.20-μm p^+ junctions when the titanium thickness is reduced to keep a high doping concentration at the $TiSi_2$/Si interface. Alternatively, a nonstandard process can be employed to implant additional dopants into the titanium. A thin layer of dopants then out-diffuses into the silicon after the silicide reaction and anneal to help reduce contact resistance and leakage currents. The latter technique is more extendable to CMOS devices which require thicker titanium films and/or shallower junctions.

Oxidation of Si-rich chemical-vapor-deposited films of tungsten silicide *by L. Krusin-Elbaum and R. V. Joshi, p. 634.* We have studied dry oxidation characteristics of Si-rich WSi_x thin films prepared by LPCVD directly on SiO_2, with $x = 2.7$ for as-deposited films. It has been reported previously that thin (less than 100 nm) CVD tungsten silicide adheres well to SiO_2. Using Auger depth profiling and Rutherford backscattering spectroscopies, we find that silicon in excess of stoichiometric WSi_2 diffuses through the silicide toward the surface to form a SiO_2 passivating overlayer. The extracted activation energy for this oxidation process is $E_a = 1.2$ eV, consistent with oxygen diffusion in SiO_2. A similar value of E_a is found for WSi_x deposited on polysilicon. During the anneal, the stoichiometry x of WSi_x decreases monotonically with the annealing temperature, reaching $x = 2$ after 30 min at 900°C or 20 min at 950°C. Longer times or higher temperatures result in silicon depletion, with $x = 1.7$ after 30 min at 1000°C. At the same time, the resistivity of WSi_x also decreases from ≈90 Ω/□ for 1500 Å as-deposited film to 5 Ω/□ for the films annealed at 1000°C, the value obtained in a standard homogenization anneal. A scanning electron micrograph (SEM) of 0.5-μm fine lines patterned using e-beam lithography reveals that the integrity of fine line structures, their adhesion to SiO_2, and their vertical profiles remain unchanged after the oxidation process. We suggest that such Si-rich tungsten silicide can be useful as a gate electrode without the polysilicon underlayer, since no extra passivation is necessary and reoxidation and homogenization steps in the FET processing sequence can be accomplished simultaneously.

Correlation analysis of particle clusters on integrated circuit wafers *by C. H. Stapper, p. 641.* Defect clustering results in correlations between the numbers of defects or faults that occur on integrated circuit chips located adjacent to one another on semiconductor wafers. Until now, it has been believed that correlations of this type were not accounted for in existing yield models. It is shown in this paper that such correlations are present in yield models based on mixed or compound Poisson statistics. A quadrat analysis of particle distributions on semiconductor wafers is used to compare data and theory. The results show that the theoretical correlation coefficients are in agreement with the experimental ones. It was also determined from the particle data how these correlation coefficients vary as the distance between quadrats is increased. This variation provides a convenient method for determining the cluster dimensions.

Modeling and analysis of computer system availability *by A. Goyal and S. S. Lavenberg, p. 651.* The quantitative evaluation of computer-system availability is becoming increasingly important in the design and configuration of commercial computer systems. This paper deals with methods for constructing and solving large Markov-chain models of computer-system availability. A set of powerful high-level modeling constructs is discussed that can be used to represent the failure and repair behavior of the components that comprise a system, including important component interactions, and the repair actions that are taken when components fail. If time-independent failure and repair rates are assumed, then a time-homogeneous continuous-time Markov chain can be constructed automatically from the modeling constructs used to describe the system. Markov chains having tens of thousands of states can be readily constructed in this manner. Therefore, techniques that are particularly suitable for numerically solving such large Markov chains are also discussed, including techniques for computing the sensitivities of availability measures with respect to model parameters. A computer system modeling example is presented to illustrate the use of these modeling and analysis techniques. The modeling constructs, automatic Markov-chain construction, and model-solution methods have been implemented in a program package called the System Availability Estimator (SAVE).

Ferroresonance *by D. M. Scoggin and J. E. Hall, Jr., p. 665.* This paper describes a mathematical model for ferroresonant circuits that addresses some of the deficiencies of earlier analyses of ferroresonant regulators. Derived using piecewise-linear, normalized differential equations, the model accommodates nonlinear behavior and predicts circuit performance in terms of parameters such as line voltage, frequency, and load. A phase-plane analysis is used to simplify the determination of linear regions of operation between nonlinear events. Numerical solutions of the resulting equations are used to generate time-domain and parametric performance curves. The results compare well with experiments and suggest potential applications in the design of high-frequency voltage regulators.

Font design for high-speed impact line printers *by J. L. Zable and H. C. Lee, p. 679.* In impact line printers that use print-band (or similar) technology, the higher speed required of the type band for higher print throughput results in wider printed strokes with increased slur. Ordinarily, font designers compensate for the increased printed strokewidth by narrowing the width of the engraved characters on the type band. While this approach corrects the total printed character stroke, the print quality is degraded because of increased slur. This paper presents an alternative design approach in which an examination of the essential parameters of print dynamics suggests a font design that incorporates wider strokewidths.

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Preface *by M. Büttiker, p. 3.*

World as system self-synthesized by quantum networking *by J. A. Wheeler, p. 4.* The quantum, strangest feature of this strange universe, cracks the armor that conceals the secret of existence. In contrast to the view that the universe is a machine governed by some magic equation, we explore here the view that the world is a self-synthesizing system of existences, built on observer-participancy via a network of elementary quantum phenomena. The elementary quantum phenomenon in the sense of Bohr, the elementary act of observer-participancy, develops definiteness out of indeterminism, secures a communicable reply in response to a well-defined question. The rate of carrying out such yes-no determinations, and their accumulated number, are both minuscule today when compared to the rate and number to be anticipated in the billions of years yet to come. The coming explosion of life opens the door, however, to an all-encompassing role for observer-participancy: to build, in time to come, no minor part of what we call *its* past—*our* past, present, and future—but this whole vast world.

Notes on the history of reversible computation *by C. H. Bennett, p. 16.* We review the history of the thermodynamics of information processing, beginning with the paradox of Maxwell's demon; continuing through the efforts of Szilard, Brillouin, and others to demonstrate a thermodynamic cost of information acquisition; the discovery by Landauer of the thermodynamic cost of information destruction; the development of the theory of and classical models for reversible computation; and ending with a brief survey of recent work on quantum reversible computation.

Miniaturization of electronics and its limits *by R. W. Keyes, p. 24.* The long-continued advance of the performance of information processing technologies has been based on miniaturization of components. The history of miniaturization is presented through examples. They suggest that limits proposed by Landauer in the 1960s will be reached in two or three decades.

Information transport obeying the continuity equation *by T. Toffoli, p. 29.* We analyze nontrivial dynamical systems in which information flows as an additive conserved quantity—and thus takes on a strikingly tangible aspect. To arrive at this result, we first give an explicit characterization of equilibria for a family of lattice gases.

Origin of life and physics: Diversified microstructure—Inducement to form Information-Carrying and Knowledge-Accumulating systems *by H. Kuhn, p. 37.* The process leading to the origin and evolution of life is caused by the presence of distinct physical and chemical conditions at a distinct location in the universe. A specified system originates and evolves under the continuous influence of a complex operational environment. The system develops toward increasing independence of the original environment by becoming increasingly complex. Modeling a detailed scenario consisting of a sequence of reasonable physico-chemical steps is essential in rationalizing the phenomenon. The basic process, accumulation of knowledge by continuously testing environmental properties, is intimately related to the measuring process in physics. Evolution is a physical process, and this process leads to man developing physics. Thus physics appears to be self-consistent—the basis and consequence of evolution. The physics-producing system is considered to be a measuring and information-processing device based upon the mechanism which operates in the origin and evolution of life.

Density of states of one-dimensional random potentials *by P. Erdös, p. 47.* Following an introduction to the early history of the theories of the density of electronic states in one-dimensional structures, pioneered, among others, by R. Landauer and J. C. Helland, a particular model, that of a multistep random potential, is discussed. It is shown that Kolmogorov-type equations can be obtained for the probability distribution of the phase of the wave function, and, by solving these equations, the density of states may be calculated. An analogy with the classical rotator in a random force field is worked out, and helps in visualizing the results.

Bloch electron in a magnetic field: Mixed dimensionality and the magnetic-field-induced generalized quantum Hall effect *by M. Y. Azbel, p. 52.* The energy spectrum of a Bloch electron in a magnetic field is one-dimensional. This leads to the Peierls instability and the magnetic-field-induced transition to the quantized Hall effect. The wave function is two-dimensional. This decreases the Peierls gap and makes it exponentially vanishing with magnetic field. Disorder lifts the degeneracy and one-dimensionality of the spectrum. High disorder yields a metallic behavior. Intermediate disorder leads to the generalized quantized Hall effect. The latter has a finite magnetoresistance as a semimetal, and Hall plateaus similar to the quantized ones, but they may have any value of the effective charge.

Residual resistivity dipoles, electromigration, and electronic conduction in metallic microstructures *by R. S. Sorbello and C. S. Chu, p. 58.* For an impurity in a bulk metal, the connection between electromigration and electric fields associated with dc conductivity is understood in terms of Landauer's residual resistivity dipole. This connection is examined, and appropriate generalizations are made for an impurity in a two-dimensional electron gas and for an impurity near a metal surface. The residual resistivity dipole field decays less rapidly with distance in a two-dimensional gas than in bulk, thus resulting in a larger voltage drop across an impurity in the system of lower dimensionality.

Coherent and sequential tunneling in series barriers *by M. Büttiker, p. 63.* A simple approach which can describe

both coherent tunneling and sequential tunneling is applied to resonant tunneling through a double-barrier structure. This approach models phase-randomizing events by connecting to the conductor a side branch leading away from the conductor to a reservoir. The reservoir does not draw or supply a net current, but permits inelastic events and phase randomization. A conductance formula is obtained which contains contributions due to both coherent and sequential tunneling. We discuss the limiting regimes of completely coherent tunneling and completely incoherent transmission, and discuss the continuous transition between the two. Over a wide range of inelastic scattering times tunneling is sequential. The effect of inelastic events on the peak-to-valley ratio and the density of states in the resonant well is investigated. We also present an analytic discussion of the maximum peak conductance e/h of an isolated resonance in a many-channel conductor.

Diffusion from an entrance to an exit *by M. E. Fisher, p. 76.* Asymptotic and exact solutions are derived from first principles by various methods for the moments of the number of steps or traversal time, etc., of a particle which diffuses, most specifically on a linear chain, to an exit site without previously leaving via an entrance site. The presentation is expository and uses standard methods.

Band tails, path integrals, instantons, polarons, and all that *by M. H. Cohen, M.-Y. Chou, E. N. Economou, S. John, and C. M. Soukoulis, p. 82.* This paper reviews the explanations recently developed by the authors and their collaborators of how disorder leads to exponential band tails and to Urbach tails in optical absorption. It starts with the simplest single-potential-well models which, despite their simplicity, are remarkably successful in accounting for the experimental facts. It then identifies the weaknesses, hidden or explicit, in these models and shows, step by step, how they can be corrected by increasing the sophistication of the procedures used. Exact results are finally achieved through use of field-theoretic techniques, and appropriately formulated single-potential-well models are shown to reproduce these quite accurately. It is also shown that the probability distribution of the random potential must be close to Gaussian, with an autocorrelation function which cuts off fairly rapidly with distance for there to be a well-defined, broad energy range in which there are exponential band tails in the density of states and Urbach tails in the optical absorption.

Fundamental questions in the theory of electromigration *by A. H. Verbruggen, p. 93.* The theory of electromigration is focused on the force acting on a lattice defect in a metallic sample that carries an electric current. Much work has been done to obtain a better understanding of the underlying physical mechanisms. The force has been calculated numerically for defects in several metals, and a qualitative agreement with the experiments has often been found. There are, however, still discussions about the relevance of certain contributions to the force. These originate from conceptual difficulties related to 1) the nature of the screening of the electric field at the site of an impurity by the conduction electrons and 2) the existence and significance of inhomogeneities in the electric field and current flow near an impurity. This paper provides a review of the basic models and of questions which still exist in the theory of electromigration. The relevance of these questions is illustrated by results of experimental work on the electromigration of H in V, Nb, and Ta.

Tunneling times and a quantum clock *by C. Foden and K. W. H. Stevens, p. 99.* The problem of measuring tunneling times by means of a quantum clock is found to lead to difficulties which are thought to arise because the Hamiltonian of the coupled system does not separate into particle and clock parts.

Coherent voltage oscillations in small normal tunnel junctions and the crossover to the incoherent regime *by Y. Gefen, p. 103.* We discuss the possibility of charge oscillations in a normal tunnel junction, driven by an external current source (I_{ex}), in the coherent limit. In that limit the dephasing time t_ϕ is larger than the period $t_p \equiv e/I_{ex}$. This behavior is modified when t_ϕ decreases.

Relative stability in nonuniform temperature *by N. G. van Kampen, p. 107.* Landauer has suggested that the relative stability of a particle diffusing in a bistable potential is affected by an intervening hot layer. We derive this effect both from thermodynamics and from the diffusion equation. For this purpose the proper form of the diffusion equation in a nonuniform medium is established for the case of a Brownian particle. If the diffusion takes place in a ring, the hot layer creates a steady current.

Boundary-layer theory for the extremely underdamped Brownian motion in a metastable potential *by H. Risken, K. Vogel, and H. D. Vollmer, p. 112.* A theory for the boundary layer near the critical trajectory for the extremely underdamped Brownian motion in a metastable potential is presented. The probability distribution function in phase space near this critical trajectory, the average escape energy, and the correction terms for the zero-friction-limit escape rate are calculated.

Bistability in active circuits: Application of a novel Fokker–Planck approach *by R. Hänggi and P. Jung, p. 119.* The problem of metastability in electronic circuits with negative differential resistance, originally pioneered by Landauer in 1962, is reconsidered from the viewpoint of a Fokker–Planck modeling for nonlinear shot noise (master equation). A novel Fokker–Planck approximation scheme is presented that describes correctly the deterministic flow and the long-time dynamics of the master equation. It is demonstrated that the conventional scheme of a truncated Kramers–Moyal expansion at the second order overestimates the transition rates in leading exponential order. In order to obtain the correct relative stability, the novel scheme uses a

diffusion coefficient which incorporates information about global nonlinear fluctuations characterized by the whole set of higher-order Kramers–Moyal transport coefficients.

Quantum noise and quantum Langevin equations *by C. W. Gardiner, p. 127.* The quantum Langevin equation of Ford, Kac, and Mazur is rederived and shown to be equivalent to an adjoint equation. This latter can be handled by means of van Kampen's cumulant expansion to yield derivations of the quasiclassical Langevin equation, stochastic electrodynamics, quantum optical, and quantum Brownian motion master equations (under appropriate conditions). The result of Benguria and Kac—that the quantum Langevin equation yields the Boltzmann distribution over energy levels in thermodynamic equilibrium—is also verified.

Symmetry and transport in disordered systems *by J. Pendry, p. 137.* The transfer matrix for a disordered system enables averages of integer powers of the resistance to be found, R^N; application of the symmetric group generalizes this formula to fractional and negative N, providing a powerful tool for the study of transport. Consequences for fluctuations in resistance, $1/f$ noise, and frequency response are discussed, as well as a new sort of state, of fractal dimension 1/2, which is responsible for transport in localized systems.

Correlated discrete transfer of single electrons in ultrasmall tunnel junctions *by K. K. Likharev, p. 144.* Recent theoretical and experimental studies have revealed a new family of effects taking place in very small tunnel junctions at low temperatures. The effects have a common origin, the correlated discrete tunneling of single electrons and/or Cooper pairs resulting from their electrostatic ("Coulomb") interaction. This paper presents a brief review of the single-electron part of the family, including discussion of the background physics, methods of theoretical description of the new effects, experimental results, and possible applications of the new effects in analog and digital electronics.

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A flexible graph-unification formalism and its application to natural-language processing *by G. Bouma, E. König, and H. Uszkoreit, p. 170.* A graph-unification-based representation language is described that was developed as the grammar formalism for the LILOG research project at IBM Germany. The Stuttgart Unification Formalism (STUF) differs from its predecessors in its higher flexibility and its algebraic structure. It is well suited for the implementation of rather different linguistic approaches, but is currently employed mainly in the development of Categorial Unification Grammars with a lexicalized compositional semantics. Examples from the syntactic and semantic processing of natural language are used to illustrate the virtues of the formalism and of our lexicalist approach to linguistic analysis.

An experiment in computational discrimination of English word senses *by E. Black, p. 185.* A number of researchers in text processing have independently observed that people can consistently determine in which of several given senses a word is being used in text, simply by examining the half dozen or so words just before and just after the word in focus. The question arises whether the same task can be accomplished by mechanical means. Experimental results are presented which suggest an affirmative answer to this query. Three separate methods of discriminating English word senses are compared information-theoretically. Findings include a strong indication of the power of domain-specific content analysis of text, as opposed to domain-general approaches.

Spelling assistance for compound words *by R. Frisch and A. Zamora, p. 195.* This paper describes a method for providing spelling assistance for Germanic compound words. The technique systematically analyzes an unknown word to determine its components, using a dictionary which associates word components with codes that describe their compounding characteristics. Language-specific morphological transformations are used to take into consideration common intraword elision patterns. Special dictionary entries, heuristic rules, and lexical distance measures are used to provide the best possible replacement compound words. The method is fast and provides spelling assistance and hyphenation support in an interactive environment.

CRITAC—An experimental system for Japanese text proofreading *by K. Takeda, E. Suzuki, T. Nishino, and T. Fujisaki, p. 201.* This paper describes an experimental expert system for proofreading Japanese text. The system is called CRITAC (CRITiquing using ACcumulated knowledge). It can detect typographical errors, Kana-to-Kanji conversion errors, and stylistic errors in Japanese text. We describe the basic concepts and features of CRITAC, including preprocessing of text, a high-level text model, Prolog-coded heuristic proofreading knowledge, and a user-friendly interface. Although CRITAC has been primarily designed for Japanese text, it appears that most of the concepts and the architecture of CRITAC can be applied to other languages as well.

Large-vocabulary speech recognition: A system for the Italian language *by P. D'Orta, M. Ferretti, A. Martelli, S. Melecrinis, S. Scarci, and G. Volpi, p. 217.* We describe a research project in automatic speech recognition which has led to the development of an experimental large-vocabulary real-time recognizer for Italian, and show how the maximum-likelihood techniques which had been employed in the development of prototype recognizers for English can be tailored to a language with substantially different characteristics.

Multilevel decoding for Very-Large-Size-Dictionary speech recognition *by B. Mérialdo, p. 227.* An important concern in the field of speech recognition is the size of the vocabulary

that a recognition system is able to support. Large vocabularies introduce difficulties involving the amount of computation the system must perform and the number of ambiguities it must resolve. But, for practical applications in general and for dictation tasks in particular, large vocabularies are required, because of the difficulties and inconveniences involved in restricting the speaker to the use of a limited vocabulary. This paper describes a new organization of the recognition process, Multilevel Decoding (MLD), that allows the system to support a Very-Large-Size Dictionary (VLSD)—one comprising over 100,000 words. This significantly surpasses the capacity of previous speech-recognition systems. With MLD, the effect of dictionary size on the accuracy of recognition can be studied. In this paper, recognition experiments using 10,000- and 200,000-word dictionaries are compared. They indicate that recognition using a 200,000-word dictionary is more accurate than recognition using a 10,000-word dictionary (when unrecognized words are included in the error rate).

A Japanese sentence analyzer *by N. Maruyama, M. Morohashi, S. Umeda, and E. Sumita, p. 238.* This paper presents the design of a broad-coverage Japanese sentence analyzer which can be part of various Japanese processing systems. The sentence analyzer comprises two components: the lexical analyzer and the syntactic analyzer. Lexical analysis, i.e., segmenting a sentence into words, is a formidable problem for a language like Japanese, because it has no explicit delimiters (blanks) between written words. In practical applications, this task is made more difficult by the occurrence of words not listed in a dictionary. We have developed a five-layered knowledge source and used it successfully in the lexical analyzer, resulting in very accurate segmentation, even in cases where there are unknown words. The syntactic analyzer has two modules: One consists of an augmented context-free grammar and the PLNLP parser; the other is the dependency structure constructor, which converts the phrase structures to dependency structures. The dependency structures represent various key linguistic relations in a more direct way. The dependency structures have semantically important information such as tense, aspect, and modality, as well as preference scores reflecting relative ranking of parse acceptability.

Conceptual graphs for the analysis and generation of sentences *by P. Velardi, M. T. Pazienza, and M. De'Giovanetti, p. 251.* A system for analyzing and generating Italian texts is under development at the IBM Rome Scientific Center. Detailed semantic knowledge on word-sense patterns is used to relate the linguistic structure of a sentence to a conceptual representation (a *conceptual graph*). Conceptual graphs are stored in a database and accessed by a natural-language query/answering module. The system analyzes a text supplied by a press-agency-release database. It consists of three modules: a morphological, a syntactic, and a semantic processor. The semantic analyzer uses a *conceptual lexicon* of word-sense descriptions, currently including about 850 entries. A description is an extended case frame providing the *surface semantic patterns* (SSP) of a word-sense *w*. SSPs express both semantic constraints and word-usage information, such as commonly found word patterns, idioms, and metaphoric expressions. SSPs are used by the semantic interpreter to build a conceptual graph of the sentence, which is then accessed by the query-answering and language-generation modules. This paper makes the claim that the SSP approach is viable and necessary to cope with language phenomena in unrestricted domains. Surface patterns are easily acquired inductively from the natural-language corpus rather than deductively from predefined conceptual structures. SSPs map quite complex sentences into surface semantic representations that can be generalized at a subsequent stage. In contrast, the current state of the art does not provide viable theory or methodology to go from superficial to deep structures. This issue is more extensively addressed in the body of the paper.

An analysis of hardware and software availability exemplified on the IBM 3725 Communication Controller *by P. I. Pignal, p. 268.* Because of the growing commercial, governmental, and scientific requirements for system availability, evaluating this factor has become increasingly important. This paper presents a unified approach to hardware and software availability of a system in the operational phase. The aim is to evaluate the availability in a given time interval, to show how to improve it, and to determine the probability that a specified level is met over the period. The inputs are the failure and repair rates of the system elements, and the functional relationship between them. Field tracking provides the failure and repair data, and Markov-chain techniques make it possible to construct, reduce, and solve the model. Availability is computed by the program package System Availability Estimator (SAVE). The model has been used and validated with actual field data for the IBM 3725 Communication Controller.

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Preface *by R. A. Webb and R. B. Laibowitz, p. 304.*

Spatial variation of currents and fields due to localized scatterers in metallic conduction *by R. Landauer, p. 306.* Volume 1 of this journal, thirty-one years ago, included a paper with the above title. Studies of small samples, in recent years, as well as earlier work on disordered samples, have caused some of the content of the earlier work to become widely understood. The aspects stressed in the title, however, relating to the spatial variations in the vicinity of a localized scattering center, have received little attention, except in electromigration theory debates. Here, we return to these aspects of the earlier paper, and emphasize that the transport field associated with a point-defect scattering center is a highly localized dipole field. The nonlinearity of resistance in terms of scattering cross section is discussed. A theory of these effects, which does justice to the coherent

multiple-scattering effects present at low temperatures, does not yet exist. Such a theory is likely to modify the effects, but it is unlikely to cause them to disappear. We also discuss closed loops, without leads; the persistent currents expected in these; and a possible method of detecting the persistent currents.

Symmetry of electrical conduction *by M. Büttiker, p. 317.* The resistance of a conductor measured in a four-probe setup is invariant if the exchange of the voltage and current sources is accompanied by a magnetic field reversal. We present a derivation of this theorem. The reciprocity of the resistances is linked directly to the microscopic reciprocity of the S-matrix, which describes reflection at the sample and transmission through the sample. We demonstrate that this symmetry holds for a conductor with an arbitrary number of leads. Since leads act like inelastic scatterers, consideration of a many-probe conductor also implies that the reciprocity of resistances is valid in the presence of inelastic scattering. Various conductance formulae are discussed in the light of the reciprocity theorem. Finally, we discuss some implications of our results for the nature of a voltage measurement and point to the difference between chemical potentials and the local electric potential.

Fluctuations in the extrinsic conductivity of disordered metal *by S. Washburn, p. 335.* Random fluctuations of the electrical conductance are ubiquitous in small (typical dimension $L < 1$ μm) metallic samples at low temperatures (typically $T < 1\text{K} \approx 0.09$ meV). The fluctuations result from the quantum-mechanical interference of the carrier wavefunctions. The superpositions of the wavefunctions depend randomly on the placement of impurities, on magnetic field, and on the current driven through the sample. At length scale L_ϕ (the average distance over which the carriers retain phase information), the fluctuations always have amplitude $\Delta G \approx e^2/h$, and any observations at scale larger than the coherence length yield a decreased amplitude of the fluctuations. Since the carrier wavefunctions are not classical, local objects (they extend over regions of size L_ϕ), the conductance contains nonlocal terms. For instance, the conductance is not zero far from the classical current paths through the sample and is not symmetric under the reversal of the magnetic field. In this article, the physics of the fluctuations is reviewed, and some of the experiments which illuminate the physics are described.

Mesoscopic coherence phenomena in semiconductor devices *by S. B. Kaplan and A. Hartstein, p. 347.* Semiconductor devices have several attractive properties which make them useful in the study of electronic coherence phenomena such as universal conductance fluctuations. The use of gated devices allows the Fermi level, and thus the electronic wavelength, to be adjusted in order to study energy correlation effects. The two-dimensional electron gas formed beneath the gate can be tilted with respect to the magnetic field to reveal that the field correlation length of the fluctuations obeys a cosine law. This strongly suggests that the fluctuations are caused by quantum interference in the same way that the Aharonov–Bohm effect arises in metallic rings. The energy range over which electrons are correlated in these materials is generally larger than in metals. This allows one to study these conductance fluctuations at much higher temperatures than are feasible in metallic conductors. For the same reason, substantially larger source–drain voltages can be applied to observe asymmetry and nonlinear effects in the conductance.

Isolated rings of mesoscopic dimensions. Quantum coherence and persistent currents *by H.-F. Cheung, Y. Gefen, and E. K. Riedel, p. 359.* Persistent currents in small nonsuperconducting rings threaded by a magnetic flux are a manifestation of novel quantum effects in submicron systems. We present theoretical results for one-channel and multichannel systems concerning the dependence of the current amplitude on the number of channels and geometry, temperature, and degree of disorder. Inelastic scattering is considered for one-channel loops only. We also discuss the observability of the effect.

Electronic transport in small strongly localized structures *by A. B. Fowler, J. J. Wainer, and R. A. Webb, p. 372.* We review some recent results on the low-temperature transport properties ($T < 4$K) of very small silicon metal-oxide field-effect transistors in the insulating regime of conduction. Our devices are lithographically patterned to have widths as small as 0.05 μm and lengths as short as 0.06 μm. These small transistors exhibit new and unexpected sample-specific fluctuation behavior in the gate voltage, temperature, and magnetic field dependence of the conductance. We discuss both resonant tunneling and Mott variable-range hopping, the two main transport mechanisms in these devices at low temperature.

What is measured when you measure a resistance?—The Landauer formula revisited *by A. D. Stone and A. Szafer, p. 384.* We re-examine the question of what constitutes the physically relevant quantum-mechanical expression for the resistance of a disordered conductor in light of recent experimental and theoretical advances in our understanding of the conducting properties of mesoscopic systems. It is shown that in the absence of a magnetic field, the formula proposed by Büttiker, which expresses the current response of a multi-port conductor in terms of transmission matrices, is derivable straightforwardly from linear response theory. We also present a general formalism for solving these equations for the resistance given the scattering matrix. This Landauer-type formula reduces to $g = (e^2/h)Tr(tt^\dagger)$, where g is the conductance and t is the transmission matrix, for the two-probe case. It is suggested that this formula provides the best description of the present class of experiments performed in two-probe or multi-probe measuring configurations, and that the subtleties leading to various different Landauer formulae are not relevant to these experiments. This is not

because of the large number of channels in real conductors, but is due to the fact that apparently no present experiment probes a "local chemical potential" in the conductor. Certain standard objections to deriving a Landauer-type formula from linear response theory are answered. Applications of this formula to fluctuations in disordered multi-probe conductors are discussed.

Scanning tunneling measurements of potential steps at grain boundaries in the presence of current flow *by J. R. Kirtley, S. Washburn, and M. J. Brady, p. 414.* We have used a new technique to simultaneously measure the surface topography and surface potential of current-carrying polycrystalline $Au_{60}Pd_{40}$ thin films using a scanning tunneling microscope. We find abrupt steps in the surface potential due to scattering from grain boundaries in these films.

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Preface *by R. B. Laibowitz and R. A. Webb, p. 440.*

Materials and processes for microstructure fabrication *by M. Hatzakis, p. 441.* The fabrication of structures considerably smaller than the devices and circuits that are mass-produced for use in computers and other electronic equipment is the subject of this paper. Devices of < 1 μm (microstructures) and < 100 nm (nanostructures) minimum dimensions were made possible in a practical sense only after the introduction of electron beams and the associated processes, as lithographic tools in the early 1960s. This paper presents a historical perspective of this very important chapter in lithographic technology, primarily from the point of view of materials and processes, since electron-beam systems are covered in other papers in this issue. In addition, the important criteria that have to be considered in the fabrication of small structures, with respect to the interaction of the writing beam with the resist material and the substrate, and the subsequent pattern-transferring processes, are discussed.

Nanolithography with a high-resolution STEM *by C. P. Umbach, A. N. Broers, R. H. Koch, C. G. Willson, and R. B. Laibowitz, p. 454.* A high-resolution scanning transmission electron microscope (STEM) with a beam diameter approaching 0.6 nm has been adapted for the patterning of complex fine-line nanostructures. An IBM PC XT is used as the pattern generator to direct the scan electronics from a Cambridge Stereoscan 250 which have been interfaced with the scanning coils of the STEM. A study of the ultimate resolution of the newly designed acid-catalyzed resist poly(p-t-butyloxycarbonyloxystyrene) has been carried out. The STEM has proven to be a flexible tool in the fabrication of individual nanostructure devices for quantum transport studies in mesoscopic devices smaller than an electron phase-coherence length.

Nanostructure technology *by T. H. P. Chang, D. P. Kern, E. Kratschmer, K. Y. Lee, H. E. Luhn, M. A. McCord, S. A. Rishton, and Y. Vladimirsky, p. 462.* The ability to fabricate structures with lateral dimensions in the sub-100-nm range has opened a new field of research. This paper first reviews recent advances in nanolithography techniques, with a brief discussion of their relative merits and fundamental limits. Special emphasis is given to the scanning electron-beam method, which is the most widely used nanolithography method at the present time. The two main areas of nanostructure research are device technology and basic science. Highlights of a number of exploratory programs in these two areas are presented.

High-throughput, high-resolution electron-beam lithography *by H. C. Pfeiffer, T. R. Groves, and T. H. Newman, p. 494.* The introduction of the shaped-beam imaging technique has greatly enhanced the exposure efficiency of electron-beam lithography systems. IBM's EL systems provide the throughput needed for lithography applications in semiconductor fabrication lines. The resolution of these systems has been steadily improved over the past 15 years in support of the semiconductor lithography trend toward submicron dimensions. This paper describes the latest version (EL-3 system) capable of fabricating 0.25-μm features. The technical challenges of submicron e-beam lithography are discussed, and practical solutions together with experimental results are presented.

Resolution limits for electron-beam lithography *by A. N. Broers, p. 502.* This paper discusses resolution limits for electron-beam fabrication. Electron beams have been used to produce structures 1 nm in size and useful devices with minimum features of about 20 nm. In all cases the resolution is set primarily by the range of the electron interaction phenomena that form the structures, and not by the size of the electron beam used to write the patterns. The beam can be as small as 0.5 nm. All useful devices built to date have been fabricated with conventional resist processes; these have an ultimate resolution of about 10 nm. Experimental data for PMMA, the highest-resolution electron resist, show that resolution is independent of molecular weight and is therefore not a function of the molecular size. The most promising of the methods offering resolution below 10 nm is the direct sublimation of materials such as AlF_3 and Al_2O_3; 1-nm structures have been fabricated, but it has not been possible to convert the structures into useful devices. In addition to the processes which use intermediate patterned layers, there is the possibility of making devices by direct modification of the electrical properties of conductors, semiconductors, or superconductors by means of high-energy electron bombardment. In these cases no intermediate fabrication process would be used, and it might be possible to reach dimensions comparable to the beam diameter.

Advanced electron-beam lithography for 0.5-μm to 0.25-μm device fabrication *by F. J. Hohn, A. D. Wilson, and P. Coane, p. 514.* High-resolution lithographic capability is required for the fabrication of fully scaled semiconductor

devices at minimum dimensions of 0.5 μm to 0.25 μm—the prototype for the semiconductor logic and memory CMOS devices of the 1990s. Electron-beam exposure tools provide this capability. Fully scaled 0.5-μm test devices were fabricated using a modified EL-3 variable shaped-electron-beam system, while 0.25-μm ground-rule lithography was accomplished with a Gaussian round-electron-beam Vector Scan system. An important part of this technology is the selection of lithographic resist system and the process used for pattern definition and transfer. Twelve or more lithographic steps are often needed for circuit devices with the above minimum dimensions. For fully scaled applications, each one of these pattern levels must be defined by electron-beam lithography, and each level may require a specific lithographic resist. Thus, the electron-beam system and the resist process must be mutually compatible if the required resolution, feature size control, and pattern-level-to-pattern-level overlay accuracy are to be achieved. This paper discusses the successful integration of e-beam lithography and resist technologies and their application to CMOS device fabrication.

Analysis of page-reference strings of an interactive system *by M. G. Kienzle, J. A. Garay, and W. H. Tetzlaff, p. 523.* The performance of real-storage-management algorithms in interactive systems suggests that locality of reference extends to a significant degree across users' transactions. This paper investigates this locality of reference by analyzing page-reference strings gathered from live systems. The data confirm the supposition: They suggest that reference patterns are dominated by system data references that are implied by the user's commands. Program references appear to play only a minor role. The user command sequence is an important factor in the reference behavior of an interactive session.

Parallel encrypted array multipliers *by S. Vassiliadis, M. Putrino, and E. M. Schwarz, p. 536.* An algorithm for direct two's-complement and sign-magnitude parallel multiplication is described. The partial product matrix representing the multiplication is converted to an equivalent matrix by encryption. Its reduction, producing the final result, needs no specialized adders and can be added with any parallel array addition technique. It contains no negative terms and no extra "correction" rows; in addition, it produces the multiplication with fewer than the minimal number of rows required for a direct multiplication process.

A many-valued logic for approximate reasoning *by S. Di Zenzo, p. 552.* A new system for many-valued logic, the Extended Post system of order p, $p \geq 2$, is proposed as a system of logic supporting reasoning with facts and rules which are reliable to a specified extent. In an Extended Post system there are as many operations of logical disjunction and logical conjunction as there are truth values. The truth value associated with a particular operation of disjunction (conjunction) acts as a threshold value controlling the behavior of the operation. The availability of an extended set of logical operations provides improved flexibility in the symbolic translation of sentences from the ordinary word-language. Extended Post systems are equipped with a semantics in which graded rather than crisp sets correspond to predicates. The system exhibits a "rich" algebraic structure. The p operations of disjunction form a distributivity cycle. To each disjunction there corresponds a dual operation of conjunction, the two operations being distributive to one another. The p conjunctions form a dual distributivity cycle. Both propositional calculus and first-order predicate calculus of *EP* systems are developed. The application to approximate reasoning is described. It is shown that there exist distinct isomorphic copies of fuzzy logic, each corresponding to a distinct level of approximation and being complete to resolution.

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Ion transport through protective polymeric coatings exposed to an aqueous phase *by H. Leidheiser, Jr. and R. D. Granata, p. 582.* This paper describes the status of work in our laboratory to develop an improved understanding of the chemical and physical aspects of ion transport through polymeric coatings which are exposed to an aqueous phase.

Characterization of PdSn catalysts for electroless metal deposition *by E. J. M. O'Sullivan, J. Horkans, J. R. White, and J. M. Roldan, p. 591.* A set of electrochemical techniques has been developed to measure the component concentrations and the catalytic activity of the PdSn seeder solutions used to activate insulating substrates for the electroless deposition of Cu. The concentration of Sn(II) was calculated from the limiting current for Sn(II) oxidation, that of Sn(IV) from the difference between the Sn metal-deposition limiting current and the Sn(II) limiting current. The palladium concentration was determined by a stripping analysis after Pd deposition from an oxidized seeder solution. The catalytic activity of the PdSn catalyst was estimated by measuring its activity for the electro-oxidation of formaldehyde (the reducing agent used in the electroless Cu bath) or by the cyclic voltammetric response of a seeded electrode in an inert electrolyte. The cyclic voltammetric technique and transmission electron microscopy examination were used to evaluate various accelerating solutions used to increase the activity of the seeder.

Chemistry at interfaces: Electropositive metals on polymer surfaces *by C. A. Kovac, J. L. Jordan-Sweet, M. J. Goldberg, J. G. Clabes, A. Viehbeck, and R. A. Pollak, p. 603.* This paper presents a study of chemical interactions between polymer surfaces and metal atoms deposited from the vapor phase. Such interactions may play an important role in interfacial metal–polymer adhesion. The chemical nature of the interface formed when an electropositive metal (chromium or cesium) is deposited onto the surface of PMDA–ODA polyimide has been investigated using chemical model studies coupled with photoelectron spectroscopic techniques. X-ray

photoelectron spectroscopy, synchrotron-radiation-excited core-level photoemission, and near-edge X-ray absorption spectroscopy were used to analyze changes in polymer surfaces during deposition of chromium and cesium. Chemical model studies using cyclic voltammetry and UV-visible spectroscopy were performed using several simpler polymers or monomeric model compounds which contained structural subunits of the polyimide. Results of these experiments show that chromium (and other electropositive metals studied so far) initially reacts rapidly with the carbonyl groups of polyimide, causing reduction of the dianhydride portion of the polymer, with concomitant chromium oxidation. Continued deposition of chromium onto the reacted polymer surface results in the formation of chromium carbide, oxide, and nitride species, indicating a disruption of the polymer chemical structure.

Characterization of a bis-maleimide triazine resin for multilayer printed circuit boards *by J. T. Gotro and B. K. Appelt, p. 616.* The thermosetting resin investigated in this study was a mixture of bis-maleimide and bis-cyanate, frequently referred to as BT (bis-maleimide triazine). For printed circuit board applications, a brominated epoxy resin was blended with BT to impart flame resistance. Resin curing was extensively investigated using a combination of thermoanalytical techniques (thermal analysis, heated-cell infrared spectroscopy, dynamic mechanical analysis, and microdielectrometry). Differential scanning calorimetry indicated a minimum of two separate reactions. Fourier-transform infrared spectroscopy provided more detailed information on the cross-linking reactions during the curing. The onset of cyclotrimerization was found to appear at 150°C, correlating with one of the peaks observed in the differential scanning calorimetry measurements. Dynamic mechanical methods were used to investigate the viscosity profile during simulated lamination temperature profiles. Microdielectrometry performed simultaneously with parallel-plate rheometry provided further insight into the physical changes that occur during lamination.

Improvement of adhesion of copper on polyimide by reactive ion-beam etching *by A. L. Ruoff, E. J. Kramer, and C.-Y. Li, p. 626.* In this paper we describe the effect of oxygen-reactive ion-beam etching of a polyimide film to enhance its adhesion to an overlying, subsequently deposited copper film. The adhesion strength of the copper to the polyimide could be increased by as much as a factor of 25 as a result of the etching. Near the etching condition which resulted in optimum strength, the failure mode at the polyimide/copper interface changed from adhesive failure to tensile failure. The latter occurred at the "roots" of a "grass-like" surface structure of the ion-etched polyimide film.

Developer-induced debonding of photoresist from copper *by A. L. Ruoff, E. J. Kramer, and C.-Y. Li, p. 631.* We describe the debonding of a polymeric photoresist film bonded to a thin copper substrate as a result of the diffusion of an organic penetrant into the polymer. The diffusion profile (measured by Rutherford backscattering spectroscopy) consisted of a uniformly swollen layer behind a sharp front which propagated into the polymer at a uniform velocity. Debonding always occurred when the front had penetrated about 12 μm into the polymer (about 1/5 its thickness). The debonding was driven by the release of elastic strain energy created by the swelling.

Physical limits to the useful packaging density of electronic systems *by R. F. Pease and O.-K. Kwon, p. 636.* Increasing the density of electronic circuits and systems has been a major thrust for many years; the benefits are increased speed, reduced power-delay product, and reduced cost. Most of this effort has been directed toward the chip, but during the last decade system performance has been increasingly limited by packaging, and so emphasis has been shifting in that direction. Initially it was believed that heat dissipation was a serious fundamental limit, but advances in heat-sink technology have effectively eliminated that concern. One of the most serious problems is signal distribution. Although we can fabricate submicron metal lines, such lines are not normally practical as chip-to-chip interconnections because their resistance leads to undue signal delay and distortion; increasing their aspect ratio will increase cross talk. It is not clear what constitutes an optimal configuration, but for metals at room temperature a signal-line pitch of 30 to 40 μm appears practical. For low temperatures, and especially for superconducting lines, the pitch could be made very much finer, leading to greatly improved system density.

Electrical design of signal lines for multilayer printed circuit boards *by C. S. Chang, p. 647.* Key aspects of the electrical design of signal lines for multilayer printed circuit boards used in computers are examined. Illustrative calculations are carried out for several signal-line configurations, and associated means are presented for selecting design trade-offs regarding cross talk and skin-effect-induced delay.

Delocalized bonding at the metal–polymer interface *by P. S. Ho, B. D. Silverman, R. A. Haight, R. C. White, P. N. Sanda, and A. R. Rossi, p. 658.* This paper summarizes our current understanding of the nature of the chemical bond formed at the interface between a deposited metal atom and an underlying polyimide surface. The approach in these studies is based on the use of quantum chemical calculations to interpret photoemission spectroscopy results. By focusing on the initial reaction between a chromium atom and the PMDA–ODA polyimide repeat unit, the bonding is demonstrated to be delocalized, arising from the formation of a charge-transfer complex between the metal atom and the PMDA unit of the polyimide. Stabilization of the complex involves the transfer of electronic charge from the metal d states of chromium to the lowest unoccupied molecular orbital of the π system of the PMDA unit of the polyimide. The complex proposed is energetically favored over that involving

a direct local interaction between the chromium atom and one of the carbonyl functional groups. The distribution of single-particle electron energy levels deduced from molecular-orbital calculations can account for the spectroscopy results. The formation of such delocalized metal–polymer complexes is also inferred from a related study of the chromium/PMDA–PDA interface.

Surface analysis and characterization of large printed-circuit-board circuitization process steps *by D. J. Auerbach, C. R. Brundle, and D. C. Miller, p. 669.* We describe our use of surface-analysis techniques to characterize problems encountered in 1980–1981 in the fabrication of large printed circuit boards for the IBM 3081 processor unit. XPS, AES, SAM, SEM, and optical microscopy techniques were used. The two major areas addressed were (a) corrosion at a photoresist/Cu foil interface during electroless Cu plating of circuit lines which resulted in defects in subsequently formed Cu lines, and (b) surface-chemical aspects of a "single-seed" colloidal Pd/Sn catalytic initiation of electroless Cu plating onto epoxy surfaces. The corrosion mechanism responsible for the line defects was identified, and corrective actions suggested. Changes in *surface* composition (Pd/Sn ratio), and *surface* chemical state (Pd^0/Pd^{2+}, Sn^0 $Sn^{2+,4+}$) as a function of process step were correlated with plating effectiveness and led to a means of increasing the surface Pd^0/Sn ratio by as much as an order of magnitude.

Elastic and viscoelastic behavior of a magnetic recording tape *by B. S. Berry and W. C. Pritchet, p. 682.* The mechanical behavior of a trilayer Mylar-based magnetic recording tape has been studied by three complementary methods, applied either to the complete tape or to samples prepared by the selective removal of its front or back coatings. One method provided tensile stress–strain and creep data, another exploited the phenomenon of thermal curling, and a third or mandrel method was used to measure relaxation and recovery in simple bending. Despite the large relative thickness of the Mylar substrate, both the initial stiffness and subsequent relaxation behavior of the tape were strongly influenced by the surface magnetic coatings, and particularly by the oriented and calendered frontcoat, which exhibited elastic anisotropy and an enhanced longitudinal Young's modulus of up to five times that of the Mylar core. As a consequence, the magnetically active frontcoat emerged as the most highly stressed component of the tape, and initially supported almost half of an imposed tensile load. The high initial modulus of the oriented and calendered frontcoat was attributed to the reinforcement provided by the magnetic oxide dispersed in the polymeric frontcoat binder. The substantial viscoelastic behavior of the coatings was also linked to their composite structure, and specifically to the ability of the binder to relax the enhanced initial modulus conferred by the presence of the oxide.

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An overview of the basic principles of the Q-Coder adaptive binary arithmetic coder *by W. B. Pennebaker, J. L. Mitchell, G. G. Langdon, Jr., and R. B. Arps, p. 717.* The Q-Coder is a new form of adaptive binary arithmetic coding. The binary arithmetic coding part of the technique is derived from the basic concepts introduced by Rissanen, Pasco, and Langdon, but extends the coding conventions to resolve a conflict between optimal software and hardware implementations. In addition, a robust form of probability estimation is used in which the probability estimate is derived solely from the interval renormalizations that are part of the arithmetic coding process. A brief tutorial of arithmetic coding concepts is presented, followed by a discussion of the compatible optimal hardware and software coding structures and the estimation of symbol probabilities from interval renormalization.

Optimal hardware and software arithmetic coding procedures for the Q-Coder *by J. L. Mitchell and W. B. Pennebaker, p. 727.* The Q-Coder is an important new development in arithmetic coding. It combines a simple but efficient arithmetic approximation for the multiply operation, a new formalism which yields optimally efficient hardware and software implementations, and a new form of probability estimation. This paper describes the concepts which allow different, yet compatible, optimal software and hardware implementations. In prior binary arithmetic coding algorithms, efficient hardware implementations favored ordering the more probable symbol (MPS) above the less probable symbol (LPS) in the current probability interval. Efficient software implementation required the inverse ordering convention. In this paper it is shown that optimal hardware and software encoders and decoders can be achieved with either symbol ordering. Although optimal implementation for a given symbol ordering requires the hardware and software code strings to point to opposite ends of the probability interval, either code string can be converted to match the other exactly. In addition, a code string generated using one symbol-ordering convention can be inverted so that it exactly matches the code string generated with the inverse convention. Even where bit stuffing is used to block carry propagation, the code strings can be kept identical.

Probability estimation for the Q-Coder *by W. B. Pennebaker and J. L. Mitchell, p. 737.* The Q-Coder is an important new development in binary arithmetic coding. It combines a simple but efficient arithmetic approximation for the multiply operation, a new formalism which yields optimally efficient hardware and software implementations, and a new technique for estimating symbol probabilities which matches the performance of any method known. This paper

describes the probability-estimation technique. The probability changes are estimated solely from renormalizations in the coding process and require no additional counters. The estimation process can be implemented as a finite-state machine, and is simple enough to allow precise theoretical modeling of single-context coding. Approximate models have been developed for a more complex multi-rate version of the estimator and for mixed-context coding. Experimental studies verifying the modeling and showing the performance achieved for a variety of image-coding models are presented.

Software implementations of the Q-Coder *by J. L. Mitchell and W. B. Pennebaker, p. 753.* The Q-Coder is an important new development in arithmetic coding. It combines a simple but efficient arithmetic approximation for the multiply operation, a new formalism which yields optimally efficient hardware and software implementations, and a new technique for estimating symbol probabilities which matches the performance of any method known. This paper describes implementations of the Q-Coder following both the hardware and software paths. Detailed flowcharts are given.

A multi-purpose VLSI chip for adaptive data compression of bilevel images *by R. B. Arps, T. K. Truong, D. J. Lu, R. C. Pasco, and T. D. Friedman, p. 775.* A VLSI chip for data compression has been implemented based on a general-purpose adaptive binary arithmetic coding (ABAC) architecture. This architecture permits the reuse of *adapter* and arithmetic *coder* logic in a universal way, which together with application-specific *model* logic can create a variety of powerful compression systems. The specific version of the *adapter/coder* used herein is the "Q-Coder," described in various companion papers. The hardware implementation is in a single HCMOS chip, to maximize speed and minimize cost. The primary purpose of the chip is to provide superior data compression performance for bilevel image data by using conditional binary source models together with adaptive arithmetic coding. The coding scheme implemented is called the Adaptive Bilevel Image Compression (ABIC) algorithm. On business documents, it consistently outperforms such nonadaptive algorithms as the CCITT Group 4 (T.6) Standard and comes into its own when adapting to documents scanned at different resolutions or which include significantly different data such as digital halftones. The multi-purpose nature of the chip allows access to internal partition combinations such as the "Q" adapter/coder, which in combination with external logic can be used to realize hardware for other compression applications. On-chip memory limitations can also be overcome by the addition of external memory in special cases. Other options include the uploading and downloading of adaptive statistics and choices to encode or decode, with or without adaptation of these statistics.

From the fractal dimension of the intermiss gaps to the cache-miss ratio *by D. Thiébaut, p. 796.* This work extends a model proposed by Voldman, Mandelbrot, et al. on the fractal nature of the gaps separating cache misses, and shows how the fractal dimension of the gap distribution can be used to predict the miss ratio experienced by the program that has generated the series of cache misses. This result supports the thesis that the fractal dimension of the distribution of the intermiss gaps is a potentially powerful measure for program characterization.

The kinetics of fast steps on crystal surfaces and its application to the molecular beam epitaxy of silicon *by R. Ghez and S. S. Iyer, p. 804.* Crystal growth by molecular beam epitaxy (MBE) occurs under conditions of high supersaturation. The classic growth theory of Burton, Cabrera, and Frank (BCF) is based on the assumption that surface steps move slowly. Consequently, it requires modifications to be applicable to MBE because the velocities of surface steps may be large. In addition, because such steps are asymmetric structures, as observed experimentally by field ion microscopy, capture probabilities from above and from below a step must differ markedly. Hence the adatom concentration distribution cannot be at equilibrium at steps; there, it also suffers a discontinuity. We propose a model that treats surface step motion as a Stefan problem and that also respects its physical asymmetry. Calculations are presented which extend and complete recently published results that had imposed the restrictive condition of local equilibrium at steps. Step velocity is estimated as a function of supersaturation, degree of asymmetry, and step density. Concentration profiles are then computed; they are found to be generally skewed. In all cases, we show that the behavior of the growing crystal is convective rather than diffusive when the supersaturation is large. Consequently, we can understand the extraordinary insensitivity of the MBE of Si to changes in growth temperature and orientation.

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The dynamics of slider bearings during contacts between slider and disk *by R. C. Benson, C. Chiang, and F. E. Talke, p. 2.* The dynamics of a "mini-Winchester" magnetic recording slider are studied during contacts with a hard, rotating memory disk using numerical simulation. An on-line solution of the Reynolds equation is used to calculate the air-film pressure, and a "coefficient-of-restitution" model is used to describe intermittent slider/disk contacts. Studies are made to identify system configurations which reduce the possibility of a "head crash" during contact start/stop.

Functional cache chip for improved system performance *by R. E. Matick, p. 15.* The use of a cache to improve the performance of computing systems is becoming very pervasive, from microprocessors to high-end systems. The general approach has traditionally been to use ordinary fast RAM chips and interface these close to the processor for speed. However, this is far from the ideal solution. The stringent and often conflicting requirements on the cache bandwidth for servicing the processor and minimizing reload time can severely limit attainable performance. The cache need not be the performance-limiting factor if a properly integrated functional cache chip is used. This paper defines the basic requirements of a cache subsystem and shows how these have been or could be implemented in typical systems. Subsequently, the functional requirements of an optimal cache chip design are presented and illustrated.

Modeling electromagnetic interference properties of printed circuit boards *by C. R. Paul, p. 33.* The mathematical modeling of a printed circuit board (PCB) for the prediction of its electromagnetic interference (EMI) properties is investigated. Two key aspects examined are crosstalk and the high-frequency voltage developed between the ends of a PCB land (ground drop). The notion of partial inductance as opposed to loop inductance is the key to predicting the high-frequency voltages that are developed between the two ends of a land. Crosstalk predictions are a by-product of the modeling. Experimental results are shown to illustrate the accuracy of the model. A technique for the accurate measurement of the high-frequency voltage developed between two ends of a PCB land is described and explained in terms of partial inductances.

Analysis of block-paging strategies *by W. H. Tetzlaff, M. G. Kienzle, and J. A. Garay, p. 51.* The performance of interactive paging systems in general and Virtual Machine/System Product (VM/SP) systems with the High Performance Option (HPO) in particular depends upon locality of reference. This storage-management dependency, often considered in the context of individual programs, extends in fact to a significant degree across most virtual-machine transactions. This paper investigates strategies to exploit locality of reference at the system level by analyzing page-reference strings gathered from live systems. Alternative strategies are evaluated using trace-driven simulations.

Statistical properties of selected recording codes *by T. D. Howell, p. 60.* Most recording systems encode their data using binary run-length-limited (RLL) codes. Statistics such as the density of 1s, the probabilities of specific code strings or run lengths, and the power spectrum are useful in analyzing the performance of RLL codes in these applications. These statistics are easy to compute for ideal run-length-limited codes, those whose only constraints are the run-length limits, but ideal RLL codes are not usable in practice because their code rates are irrational. Implemented RLL codes achieve rational rates by not using all code sequences which satisfy the run-length constraints, and their statistics are different from those of the ideal RLL codes. Little attention has been paid to the computation of statistics for these practical codes. In this paper a method is presented for computing statistics of implemented codes. The key step is to develop an exact description of the code sequences which are used. A consequence of the code having rational rate is that all the code-string and run-length probabilities are rational. The method is illustrated by applying it to three codes of practical importance: MFM, (2, 7), and (1, 7).

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Geometric tolerancing: I. Virtual boundary requirements *by R. Jayaraman and V. Srinivasan, p. 90.* We examine the representation of geometric tolerances in solid-geometric models from the perspective of two classes of functional requirements. The first class deals with positioning of parts with respect to one another in an assembly, and the second with maintaining material bulk in critical portions of parts. Both are directly relatable to the geometry of the parts. Through examples, we demonstrate that these functional requirements can be captured in a specific form of tolerances designated as virtual boundary requirements (VBRs). We further demonstrate that the only proposed theory of tolerances in solid models, and the current dimensioning and tolerancing standards in industrial practice, are both inadequate for dealing with VBRs. Accordingly, we develop a theoretical basis for the rigorous statement and interpretation of VBRs.

Geometric tolerancing: II. Conditional tolerances *by V. Srinivasan and R. Jayaraman, p. 105.* In a companion paper, we examined the representation of geometric tolerances in solid models from the perspective of certain functional requirements. We showed that assembly and material bulk requirements can be specified as virtual boundary requirements (VBRs). Here, we study the related issue of deriving equivalent alternative specifications. Specifically, we first explore the reasons for converting VBRs to another form of tolerances designated as conditional tolerances (CTs). We then develop a theoretical basis for converting VBRs to CTs and derive CTs for some common and practical VBRs.

We thereby demonstrate the difficulties in finding a general-purpose algorithm for such conversions and also show that some of the CT formulas used in current practice are incorrect.

Conjugate-gradient subroutines for the IBM 3090 Vector Facility *by G. R. di Brozolo and M. Vitaletti, p. 125.* This paper describes a set of optimized subroutines for use in solving sparse, symmetric, positive definite linear systems of equations using iterative algorithms. The set has been included in the Engineering and Scientific Subroutine Library (ESSL) for the IBM 3090 Vector Facility (VF). The subroutines are based on the conjugate-gradient method, preconditioned by the diagonal or by an incomplete factorization. They make use of storage representations of sparse matrices that are optimal for vector implementation. The ESSL vector subroutines are up to six times faster than a scalar implementation of the same algorithm.

Lattice-gas hydrodynamics on the IBM 3090 Vector Facility *by S. Succi, D. d'Humières, and F. Szelényi, p. 136.* After a brief review of the means for characterizing lattice gases using cellular automata rules, we discuss the implementation of the rules for simulating hydrodynamic phenomena which can be described by the Navier–Stokes equations. Special emphasis is placed on data-mapping strategies and implementation through the use of the high speed and large memory resources offered by vector multiprocessors such as the IBM 3090 Vector Facility. We present performance data which pertain to square and hexagonal lattice gases, and discuss the limits of the approach used and its potential extendability to other areas.

A method for generating weighted random test patterns *by J. A. Waicukauski, E. Lindbloom, E. B. Eichelberger, and O. P. Forlenza, p. 149.* A new method for generating weighted random patterns for testing LSSD logic chips and modules is described. Advantages in using weighted random versus either deterministic or random test patterns are discussed. An algorithm for calculating an initial set of input-weighting factors and a procedure for obtaining complete stuck-fault coverage are presented.

Large-area fault clusters and fault tolerance in VLSI circuits: A review *by C. H. Stapper, p. 162.* Fault-tolerance techniques and redundant circuits have been used extensively to increase the manufacturing yield and productivity of integrated-circuit chips. Presented here is a review of relevant statistical models which have been used to account for the effects on manufacturing yield of the large-area defect and fault clusters commonly encountered during chip fabrication. A statistical criterion is described for determining whether such large-area clusters are present.

Small-area fault clusters and fault tolerance in VLSI circuits *by C. H. Stapper, p. 174.* In previous treatments of the manufacturing yield of fault-tolerant integrated-circuit chips, fault clusters were either assumed to be absent or relatively large in area. Presented here is a treatment in which the occurrence of small-area fault clusters is assumed. Four different types of statistical distributions are considered, and a criterion is described for determining whether small-area fault clusters are present.

Translating object specifications into a computer-generated three-dimensional graphic to be reproduced as a high efficiency, reflection photo-polymer hologram suitable for mass-production *by W. J. Molteni, Jr. and D. Small, p. 178.* A process is described for translating the specifications of an object and its interrelationship with another object into a three-dimensional computer graphic and then into a photo-polymer hologram. The capability to translate specifications about objects and their interrelationships into accurate holograms without having to create either a physical model or the manufactured object itself opens exciting possibilities in the areas of creative design and communication. It may assist in the manufacturing process by allowing designers to specify objects and to study accurate, three-dimensional representations of those specifications, including interrelationships with other objects, without the need for an actual physical model. Finally, the hologram may become a means for effective representation of an image produced through the use of three-dimensional computer graphics for people without access to appropriate computer graphics. The process described here was divided into two segments. The MIT Media Lab was responsible for creating a sequence of computer-generated images and transferring those images to film. Polaroid Corporation was responsible for creating the hologram from the images on film.

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Preface *by K. A. Müller and J. G. Bednorz, p. 199.*

Current understanding of electronic structure and some difficulties with cuprate semiconductors *by K. Kitazawa, p. 201.* Experimental observations of the high-T_c cuprate superconductors are reviewed from the perspective of electronic structures. On the basis of Mott–Hubbard-type band splitting, the semiconductivity, antiferromagnetism, and metallic nature of the cuprate oxides are discussed as a function of the dopant concentration. Then the involvement of the O $2p$ band which falls between the lower and upper Hubbard bands, as determined by electron spectroscopy, is discussed. Finally, the complex nature of the Fermi surface is considered, and the importance of the involvement of both the O $2p$ and the lower Hubbard band is stressed.

High-T_c superconductivity in bismuthates—How many roads lead to high T_c? *by B. Batlogg, R. J. Cava, L. F. Schneemeyer, and G. P. Espinosa, p. 208.* The superconducting transition temperature in $BaBiO_3$-based superconductors exceeds 30K. Magnetic measurements are analyzed to give their density of states at E_F, $N^*(0) \propto \gamma$. The

uniqueness of Bi–O and Cu–O superconductors is revealed in an updated T_c–γ plot. The two classes of compounds share basic electronic properties, particularly a partially unoccupied band with significant O 2*p* character, which might favor a common pairing mechanism.

Interim report on the charge-transfer resonance model for the Cu–O superconductors *by C. M. Varma, p. 215.* The two-band model including intra-atomic repulsion on Cu and near-neighbor Cu–O repulsion for the high-temperature superconductors is supported by a variety of experiments and theoretical calculations as the minimum necessary. The specific mechanism for high T_c through charge-transfer resonances was proposed because the known alternative mechanisms—phonons and magnetic excitations—were believed unlikely. The case for charge-transfer-resonance-induced high T_c has, however, not yet been proven. Equally important, the various anomalies in the metallic state are not yet understood. However, calculations on the model do show a charge-transfer-gap insulating state which is antiferromagnetic at and near 1/2 filling, a metallic state for intermediate filling with effective particle–particle attraction, and a charge-transfer instability beyond a certain filling.

Oxygen "disorder" and the structures of high-T_c superconductors by neutron powder diffraction *by A. W. Hewat, E. A. Hewat, P. Bordet, J.-J. Capponi, C. Chaillout, J. Chenavas, J.-L. Hodeau, M. Marezio, P. Strobel, M. François, K. Yvon, P. Fischer, and J.-L. Tholence, p. 220.* All of the high-T_c perovskite superconductors appear to show disorder of certain oxygen atoms. In $(La,Sr)_2CuO_4$ and perhaps also in $YBa_2Cu_3O_7$ this is associated with a structural transition. The Bi and Tl superconductors, for which we now have neutron structural data on four different phases, also show oxygen "disorder" which may be associated with valence fluctuations. In $Tl_2Ba_2CuO_6$, electron holes are created by the absence of 1/8 of the atoms in the TlO plane, producing a marked superstructure. However, this material is not superconducting if the superstructure is well ordered, with an orthorhombic (strictly monoclinic) structure. The T_c appears to depend on the disorder of the superstructure to produce a pseudotetragonal metric in which the oxygen atoms within the TlO plane are distributed over four equivalent sites about the center of the Tl square.

Tl–Ca–Ba–Cu–O superconducting oxides *by R. B. Beyers, S. S. P. Parkin, V. Y. Lee, A. I. Nazzal, R. J. Savoy, G. L. Gorman, T. C. Huang, and S. J. La Placa, p. 228.* This paper reviews structural studies of Tl–Ca–Ba–Cu–O superconducting oxides by the authors and others and points out directions for future work.

Infrared studies of the normal and superconducting states of $Y_1Ba_2Cu_3O_7$ *by R. T. Collins, Z. Schlesinger, F. H. Holtzberg, P. Chaudhari, and C. A. Feild, p. 238.* We describe infrared measurements of the *a*–*b*-plane response of $Y_1Ba_2Cu_3O_7$ crystals with $T_c \approx 92$K. We observe a self-energy structure at a characteristic energy of 500 cm^{-1} ($8kT_c$), the appearance of which coincides with the transition to the superconducting state. The nature of this self-energy anomaly is consistent with its identification as a nodeless *a*–*b*-plane energy gap at $2\Delta \approx 8kT_c$. On the basis of temperature-dependent measurements above T_c, we suggest that the normal state can be primarily characterized by a carrier band with an enhanced low-frequency mass and a frequency-dependent scattering rate. Our data indicate that these arise from coupling to an excitation spectrum with characteristic frequencies up to $\omega_c \sim 700$ cm^{-1} and a coupling strength of $\lambda \approx 2$–3.

On the nature of high-temperature superconductivity *by V. J. Emery, p. 246.* A picture of the electronic structure, magnetism, and superconductivity in high-T_c oxides is obtained from a simple analysis of experiments and models of the copper oxide planes. It is shown that magnetism is associated with holes on copper and superconductivity with holes on oxygen. The pairing force is not retarded. Questions about the motion of charges in an antiferromagnetic background and the many-body theory of high-temperature superconductivity are discussed. Differences between the cuprates and doped $BaBiO_3$ are emphasized.

Measurements on thin-film high-T_c superconductors *by A. Kapitulnik and K. Char, p. 252.* We report on the fabrication and properties of high-T_c superconducting films, and discuss the possible origin of the linear resistivity. We further discuss the *c*-axis conductivity. We present data to show that the coherence length is 12 Å parallel to the plane and 2 Å perpendicular to the plane in the superconducting state. Tunneling data show that the energy gap is large, with $2\Delta/kT_c \approx 7$.

Granular Josephson and quantum interference effects in HTC ceramic superconductors *by C. E. Gough, p. 262.* Josephson effects in high-T_c superconductors are briefly reviewed, with specific reference to granular ceramic materials and SQUID device applications. It is suggested that the inductance associated with intergranular current loops may play an important role, even in determining the bulk superconductivity properties, as in weak-link superconducting rings. Evidence for quantum interference effects within intergranular current loops is presented. In ultra-low fields, the observed temperature dependence of thermally activated flux creep cannot be described by a simple granular superconductor model of equally spaced pinning centers, but would seem to imply a hierarchy of pinning sites of variable strength. The development of liquid-nitrogen-cooled rf and dc SQUIDs is described, and the noise levels currently achieved are presented.

Quasi-elastic and inelastic neutron-scattering studies of superconducting $La_{2-x}Sr_xCuO_4$ *by R. J. Birgeneau, Y. Endoh, Y. Hidaka, K. Kakurai, M. A. Kastner, T. Murakami, G.*

Shirane, T. R. Thurston, and K. Yamada, p. 270. We review the results of recent neutron-scattering studies of the spin fluctuations in samples of $La_{1.89}Sr_{0.11}CuO_4$ which are ~80% superconducting with $T_c = 10K$. The structure factor, $S(\vec{Q})$, reflects three-dimensional modulated spin correlations with an in-plane correlation length of order 18 ± 6 Å. The fluctuations evolve with temperature from being predominantly dynamic at high temperatures to mainly quasi-elastic ($|\Delta E| < 0.5$ meV) at low temperatures. No significant differences are observed in the normal and superconducting states.

NMR study of magnetism and superconductivity in high-T_c oxides *by Y. Kitaoka, K. Ishida, K. Fujiwara, K. Asayama, H. Katayama-Yoshida, Y. Okabe, and T. Takahashi, p. 277.* The results of ^{139}La and ^{63}Cu nuclear quadrupole resonance (NQR) on La–Ba,Sr–Cu–O, Y–Ba–Cu–O, and Bi–Pb–Sr–Ca–Cu–O compounds and of ^{17}O nuclear magnetic resonance (NMR) on Y–Ba–Cu–O are extensively reviewed. As for the magnetism, the phase diagram for the La system studied by a ^{139}La NQR experiment is presented, with evidence of the disordered magnetic state between the 3D-antiferromagnetic (AF) ordered state and the superconducting state. With respect to its superconducting nature, the nuclear spin-lattice relaxation behavior (T_1) of Cu in the CuO_2 plane has been found to be unconventional above and below T_c for all compounds, with no signatures expected for a nonmagnetic metal and a BCS superconductor, respectively. The behavior of T_1 of Cu above T_c is shown to be dominated by AF fluctuation of Cu *d* spins. In contrast, an enhancement of $1/T_1$ of ^{17}O has been observed just below T_c, which is similar to a BCS case.

Magnetic frustration model and superconductivity in doped planar CuO_2 systems *by A. Aharony, R. J. Birgeneau, and M. A. Kastner, p. 287.* We present a model for the magnetic phases and superconductivity in doped planar CuO_2 systems. Electronic holes on the oxygen ions introduce local ferromagnetic exchange couplings between the Cu spins. The resulting frustration destroys the antiferromagnetic state characterizing the undoped planes, and generates a new spin-glass phase. This frustration also yields an attractive interaction between the holes, whose range decreases with increasing doping. We use the BCS approximation to obtain an excellent estimate of the superconducting transition temperature $T_c(x)$ for $La_{2-x}Sr_xCuO_4$.

Short-coherence-length superconductors *by G. Deutscher, p. 293.* The new high-T_c oxides present some anomalous electromagnetic properties, such as low critical current densities, a reversible behavior of the magnetization at fields much lower than H_{c2}, and internal Josephson effects, that distinguish them from the conventional low-T_c metals and alloys. These anomalous properties were first observed in bulk-sintered samples and were often ascribed to the poor connectivity of these ceramics. More recently, a qualitatively similar behavior has been observed in single crystals and oriented films. The fundamental role of the short coherence length in determining the behavior of the high-T_c oxides is discussed. We show that the short coherence lengths at the local depressions of the order parameter at crystallographic defects lead to reduced critical currents and cause glassy behavior in the vicinity of T_c.

Critical current measurements in single crystals and single-grain boundaries in $YBa_2Cu_3O_7$ films *by P. Chaudhari, D. Dimos, and J. Mannhart, p. 299.* The temperature, magnetic field, and orientation dependence of the critical current density of superconducting $YBa_2Cu_3O_7$ films have been determined from transport measurements. The results support a model of flux creep within single grains and weak-link coupling across grain boundaries.

Glassy behavior of high-T_c superconductors *by I. Morgenstern, p. 307.* This paper deals with the question of flux creep or glassy behavior in high-T_c superconducting single crystals. It is shown that the flux creep picture is merely a phenomenological approach to the glassy behavior for relatively short times and low temperatures. Glassy effects are predicted for temperatures between 70% and 95% T_c and magnetic fields in the range of 0.03 T to 0.2 T. The glass concept can be understood as a generalization of the traditional flux creep picture. A hierarchy of energy barriers dominates the physical behavior. An important technical aspect is the influence of the glassiness on critical currents.

Muon-spin rotation experiments in high-T_c superconductors and related materials *by H. Keller, p. 314.* Recent muon-spin rotation μSR experiments in high-T_c superconductors and related antiferromagnetic materials are reviewed. The possibilities and the limitations of the μSR method for investigating these materials are briefly discussed. In a high-T_c superconductor, μSR is an ideal tool with which to study the local magnetic field distribution at the muon site, allowing a determination of the London penetration depth. It is further shown that μSR experiments may contribute to the microscopic understanding of the superconducting glass state in the high-T_c oxides. In the related antiferromagnetic materials μSR is a sensitive method for detecting frozen local magnetic moments.

Low-field microwave absorption in single-crystal superconducting $YBa_2Cu_3O_{7-\delta}$ *by K. W. Blazey and F. H. Holtzberg, p. 324.* The low-field microwave absorption line spectrum of single crystal of superconducting $YBa_2Cu_3O_{7-\delta}$ has been studied as a function of the external magnetic field. The threshold microwave power necessary to nucleate fluxons is found to vary with field in such a way that only about one thousandth of the junction length is active in interacting with the microwaves to create fluxons.

Memory effects in $YBa_2Cu_3O_{7-\delta}$ single crystal *by C. Rossel, Y. Maeno, and F. H. Holtzberg, p. 328.* Measurements of the time dependence of zero-field-cooled (ZFC) and field-cooled

(FC) magnetization M in $YBa_2Cu_3O_{7-\delta}$ single crystal have been performed as a function of temperature and magnetic field. The appearance of an echo-like feature in the decay rate $S = dM/d \ln t$ at an observing time t equal to the waiting time t_w during which the specimen was prepared at a given field H_0 and temperature T reveals aging effects in the superconducting state. Similar phenomena reported in spin glasses seem to validate the picture of a superconducting glass state in $YBa_2Cu_3O_{7-\delta}$.

Positron annihilation and high-temperature superconductivity *by M. Peter, p. 333.* After a brief review of the theory of positron annihilation techniques and of experimental principles, we give examples of the successful determination of electron momentum density and Fermi surfaces in alkali metals, transition elements and compounds, and cerium. We then discuss the application of positrons in superconducting oxides. So far the best results have been obtained in $YBa_2Cu_3O_{7-x}$, with confirmation of calculated band structure and observation of discontinuity at the Fermi energy.

Nuclear magnetic resonance in high-T_c superconductors *by M. Mehring, p. 342.* This paper is aimed at the nonspecialist in nuclear magnetic resonance who wants to know what NMR can do to increase his understanding of high-T_c superconductors. Most NMR results are discussed in an illustrative manner to facilitate intuitive understanding. Several specific NMR experiments are presented which demonstrate the variety of this experimental technique. Special emphasis is given to the following aspects: ionic charges and quadrupole interaction, local fields and magnetic ordering, conduction electrons and Knight shifts, quasiparticle excitations, and nuclear spin-lattice relaxation.

Critical temperature and the Ginzburg–Landau theory of layered high-temperature superconductors *by T. Schneider, p. 351.* Using the mean-field approximation, we study a model for quasi-two-dimensional superconductors. The interlayer coupling, assumed to be mediated by a small electron-hopping term, is found to leave T_c practically unaffected. Thus, a three-dimensional pairing mechanism is required to explain the observed rise in T_c with decreasing average layer spacing in the Bi and Tl compounds. Taking the inhomogeneities of intrinsic or extrinsic nature into account, we find, in the dirty limit, corrections to the conventional anisotropic Ginzburg–Landau behavior—an upward curvature of the upper critical fields which appears to be a universal feature of layered superconductors.

Instability and high-T_c superconductivity *by M. Kataoka, p. 356.* The interrelation between instability and a high superconducting transition temperature T_c is argued theoretically in order to construct a model for the origin of the high T_c in the perovskite-type oxides. It is shown that when two nearly degenerate bands overlapping on the Fermi energy ε_F become unstable against spontaneous splitting to give rise to a charge redistribution, effective interactions between two electrons in the same bands become attractive, and the attractive interactions are strongly enhanced by increasing the degree of instability. One cause of this instability is the electron–phonon coupling, which results in lattice-instability-enhanced superconductivity; another cause is the Coulomb interaction between electrons, which results in electron-instability-caused superconductivity. The latter mechanism is successfully applied to the perovskite-type high-T_c superconductors. Some guidelines for obtaining a high T_c are presented on the basis of the present idea.

A review of elastic properties of high-T_c superconductors and some related C_p results *by K. Fossheim and T. Lægreid, p. 365.* First a brief survey is given of what can be learned about important superconducting and normal-state properties by ultrasonic and other elastic measurements. Some of the characteristic elastic properties of the $La_{2-x}(Ba, Sr)_xCuO_4$ and $YBa_2Cu_3O_7$ systems are reviewed. In the La-based family it is shown how the elastic observations are closely related to structural and soft-mode properties. The physics of $YBa_2Cu_3O_7$ is shown to be more complex. Finally, our recent results on the fluctuation contribution to the specific heat near T_c in $YBa_2Cu_3O_7$ are discussed.

Electronic structure studies of high-T_c superconductors by high-energy spectroscopies *by J. Fink, N. Nücker, H. A. Romberg, and J. C. Fuggle, p. 372.* A review of our high-energy spectroscopy studies of the electronic structure of the new high-T_c superconductors is given. X-ray-induced photoelectron spectroscopy, bremsstrahlung–isochromat spectroscopy, Auger electron spectroscopy, and electron energy-loss spectroscopy have been used. Parameters determining the correlated electronic structure have been derived, together with information on the nature and the symmetry of the charge carriers.

A new structural modification of superconducting $La_{2-x}M_xCuO_4$ *by J. D. Axe, D. E. Cox, K. Mohanty, H. Moudden, A. R. Moodenbaugh, Y. Xu, and T. R. Thurston, p. 382.* $La_{1.9}Ba_{0.1}CuO_4$ has been observed to undergo the following sequence of transformations upon cooling from 300K: tetragonal ($I4/mmm$) $\rightarrow$ ($T_0 = 270$K) orthorhombic (Cmca) $\rightarrow$ ($T_1 = 52$K) tetragonal ($P4_2/ncm$). The newly discovered low-temperature tetragonal structure can be understood geometrically as arising from a coherent superposition of the two domain modifications of the orthorhombic structure. Dynamically, it results from a second instability in the twofold degenerate soft modes of the high-temperature tetragonal phase. Energetically, the system can be modeled as an XY-spin system with temperature-dependent quartic anisotropy $v(T)$, and the low-temperature transformation coincides with an isotropic point $v(T_1) = 0$. The relationship of the newly discovered transformation to other anomalous properties and to superconductivity is discussed briefly.

Energy dependence of the Andreev reflection of $YBa_2Cu_3O_{7-\delta}$ *by H. van Kempen, H. F. C. Hoevers, P. J. M. van Bentum, A. J. G. Schellingerhout, and D. van der Marel, p. 389.* Measurements of the energy dependence of the Andreev reflection have been performed on a $Ag–YBa_2Cu_3O_{7-\delta}$ interface. The observation of the Andreev reflection indicates a ground state of zero-momentum pairs. It is shown that, in principle, the bulk Δ (electron pair potential) can be determined from the energy dependence of the Andreev reflection. In the present experiment, however, due to the limited mean free path of the electrons in the silver, only a lower limit of Δ was found.

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Modeling and image processing for visualization of volcanic mapping *by M. T. Pareschi and R. Bernstein, p. 406.* In countries such as Italy, Japan, and Mexico, where active volcanoes are located in highly populated areas, the problem of risk reduction is very important. Actual knowledge about volcanic behavior does not allow deterministic event prediction or the forecasting of eruptions. However, areas exposed to eruptions can be analyzed if eruption characteristics can be inferred or assumed. Models to simulate volcanic eruptions and identify hazardous areas have been developed by collaboration between the IBM Italy Pisa Scientific Center and the Earth Science Department of Pisa University (supported by the Italian National Group of Volcanology of the Italian National Research Council). The input to the models is the set of assumed eruption characteristics: the typology of the phenomenon (ash fall, pyroclastic flow, etc.), vent position, total eruptible mass, wind profile, etc. The output of the models shows volcanic product distribution at ground level. These models are reviewed and their use in hazard estimation (compared with the more traditional techniques currently in use) is outlined. Effective use of these models, by public administrators and planners in preparing plans for the evacuation of hazardous zones, requires the clear and effective display of model results. Techniques to display and visualize such data have been developed by the authors. In particular, a computer program has been implemented on the IBM 7350 Image Processing System to display model outputs, representing both volume (in two dimensions) and distribution of ejected material, and to superimpose the displays upon satellite images that show 3D oblique views of terrain. This form of presentation, realized for various sets of initial conditions and eruption times, represents a very effective visual tool for volcanic hazard zoning and evacuation planning.

Natural quadrics: Projections and intersections *by M. A. O'Connor, p. 417.* Geometrical modelers usually strive to support at least solids bounded by the results of Boolean operations on planes, spheres, cylinders, and cones, that is, the natural quadrics. Most often this set is treated as a subset of the set of quadric surfaces. Although the intersection of two quadrics is a mathematically tractable problem, in implementation it leads to complexity and stability problems. Even in the restriction to the natural quadrics these problems can persist. This paper presents a method which, by using the projections of natural quadrics onto planes and spheres, reduces the intersection of two natural quadrics to the calculation of the intersections of lines and circles on planes and spheres. In order to make the claims of the method easily verifiable and provide the tools necessary for implementation, explicit descriptions of the projections are also included.

Femtosecond laser studies of the relaxation dynamics of semiconductors and large molecules *by C. L. Tang, F. W. Wise, M. J. Rosker, and I. A. Walmsley, p. 447.* The use of femtosecond lasers and the related optical correlation spectroscopic technique for studying the relaxation dynamics of semiconductors and photoexcited molecules are reviewed. In particular, the results on the intraband relaxation of nonequilibrium carriers in GaAs and related compounds and quantum well structures are summarized. The optical correlation technique also led to the observation of quantum beats in the femtosecond time domain corresponding to the direct observation of molecular vibrations in the time domain.

Effects of quasiperiodic (Penrose tile) symmetry on the eigenvalues and eigenfunctions of the wave equation *by S. He and J. D. Maynard, p. 456.* In addition to the basic crystalline and amorphous structures for solids, it is possible that solids may also form with a quasiperiodic, or Penrose tile, structure. A current problem in condensed-matter physics is to determine how this structure affects the various physical properties of a material. A fundamental question involves the consequences of quasiperiodic symmetry in the eigenvalue spectrum and eigenfunctions of a wave equation. While rigorous theorems have been derived for one-dimensional systems, there is currently no known "quasi-Bloch theorem" for two and three dimensions. To gain insight into this problem, an acoustic experiment has been used to study a two-dimensional wave system with a Penrose tile symmetry. The results show an eigenvalue spectrum containing bands and gaps with widths which are in the ratio of the Golden Mean, $(\sqrt{5}+1)/2$.

Time series in *M* dimensions: The power spectrum *by R. H. Yetzer, p. 464.* The approach presented here extends the modeling of *M*-dimensional (spatial) time series from the time domain into the frequency domain. The autocovariance function for an *M*-dimensional time series is transformed to obtain the power spectrum in *M* dimensions. The latter describes the variance within the series and can be used to identify dependencies and/or test the adequacy of a fitted model. An example is provided.

Two-level coding for error control in magnetic disk storage products *by A. M. Patel, p. 470.* Error-control coding has played a significant role in the design and development of magnetic recording storage products. The trend toward higher densities and data rates presents continuing demands

for an ability to operate at a lower signal-to-noise ratio and to tolerate an increased number of correctable errors.
Heretofore, the magnetic disk storage products used coding schemes that provided correction of one burst of errors in a record of length ranging from a few bytes of data to a full track on the disk. In this paper, we present a new coding architecture that facilitates correction of multiple-burst errors in each record in a typical disk storage application. This architecture embodies a two-level coding scheme which offers high coding efficiency along with a fast decoding strategy that closely matches the requirements of on-line correction of multiple bursts of errors. The first level has a smaller block delay and provides very fast correction of most of the errors commonly encountered in an average disk file. The second level, on a larger block size, provides reserve capability for correcting additional errors which may be encountered in a device with symptoms of a weaker component or an oncoming failure. The new IBM 3380J and 3380K disk files use a two-level scheme that is designed around the coding structure of the extended Reed–Solomon code. This design and the related encoding and decoding methods and implementation are presented in detail.

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Frames, semantic networks, and object-oriented programming in APL2 *by M. Alfonseca, p. 502.* This paper discusses the capabilities of APL2 for the implementation of frame systems and semantic networks, and for the use of object-oriented programming techniques. The fact that the frame is a basic data structure of APL2 makes this language very appropriate for the development of artificial intelligence applications using the indicated techniques. Examples are given of the way in which they may be applied to realistic situations.

Dependability evaluation of a class of multi-loop topologies for local area networks *by W. E. Smith and K. S. Trivedi, p. 511.* Local area networks have been developed using both ring and bus topologies. Multi-loop and multi-connected topologies have been proposed to improve the throughput and dependability of single-loop networks. We evaluate the dependability of a class of multi-connected loop topologies called forward loop, backward hop (FLBH) networks and compare them to simple ring networks.

Architecture, design, and operating characteristics of a 12-ns CMOS functional cache chip *by R. Matick, R. Mao, and S. Ray, p. 524.* The architecture, design, and implementation of a high-performance cache require a detailed consideration of the overall system functions closely coupled with the proper mapping and integration of these functions into the circuits and arrays. This approach has resulted in a new cache chip which incorporates a number of unique on-chip functions as well as unique design, providing a one-cycle cache in which translation can be overlapped with cache access. In order to achieve high average performance, a cache should give the appearance of being a two-ported array in order to provide high bandwidth both to the processor during normal execution and to the main memory during reload. But a true two-port design is undesirable as well as unnecessary, especially since the reload process is typically limited by the memory speed and other system parameters. A significant improvement can be obtained by judicious choice as well as proper integration of some critical functions placed directly on the cache chips. This paper describes these functions and integration onto a 72K-bit static RAM chip, implemented in 1-μm CMOS technology for high speed and overall system performance. In addition, the chip I/O is selectable for either ECL or TTL compatibility.

Order in the domain structure in soft-magnetic thin-film elements: A review *by H. A. M. van den Berg, p. 540.* The domain structure and its development in thin plane-parallel soft-magnetic elements have been investigated from both the experimental and the theoretical point of view. The experimental observations for verifying the predictions have been realized by means of the Bitter, Kerr, and Lorentz techniques.

In the first part, a self-consistent domain theory, based on micromagnetic principles, is unfolded for two-dimensional solenoidal magnetization distributions present in ideally soft-magnetic thin-film objects that are rectangular cylinders. The solenoidality implies that both the external field and the conduction currents are taken as zero. Two types of domain structures are distinguished: the basic structures in simply connected regions and the parallel configurations in special types of multiply connected regions—the parallel regions. A decomposition of the area of the object into disjunct subregions, either simply connected or of the parallel type, whose union completely covers the object, is put forward. A procedure for constructing all feasible parallel regions is presented. In each region, the appropriate solenoidal magnetization distribution is specified with which the magnetization M is taken parallel to the boundaries of the subregion. Thus, all the domain structures possible in the thin-film objects with arbitrary lateral shapes can be constructed. A number of experimental examples are provided.

In the second part, the M distribution is studied on a local scale, at which the requirement of solenoidality is dropped; i.e., external fields and conduction currents are allowed. The concept of the domain-wall cluster is introduced in order to obtain the maximum information about the M configuration in the entire object. Here, we employ the fact that domain walls are the preeminently visible features and that most information is available at those locations where a number of these walls meet. A domain-wall cluster is the collection of all domain walls that have one region—the so-called cluster knot—in common. Three different categories of clusters characterized by the positions of their cluster knots with respect to the edges of the thin-film object are distinguished.

Wall clusters with cluster knots at two, one, and no edges are defined as the corner, edge, and free clusters, respectively. General features of the magnetization distribution near the cluster knots are discussed for each of the above classes. The reversible transformations of the clusters are reviewed. Two different types of these conversions are recognized, to wit the cluster creation (fading) and the cluster furcation (fusion). Experimental evidence of these relationships is provided.

In the third part, the domain structures are considered as a concatenation of domain-wall clusters. During the domain-structure transformations, clusters are added to and removed from the domain-wall network. The conversions are reversible along specific branches of the hysteresis curves at which the changes can be comprehended in terms of the above reversible cluster conversions. Notwithstanding the reversible character at these branches, the domain configuration often develops itself into a subminimum of the energy, from which sudden irreversible transformations take place toward other branches with lower energy. In many cases, the latter alterations are attended by jumpwise adaptations in the overall object magnetization component along the field, and reveal themselves in the hysteresis curve. The part of the internal domain-wall structure in the hysteresis is elucidated, and its dependence on the film thickness is emphasized. Many examples are given for the purpose of demonstrating the strongly interwoven character of the domain network, the prehistory in the magnetic sense, the internal structure of the domain walls, and the macroscopic object hysteresis.

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Coding for constrained channels: A comparison of two approaches *by P. A. Franaszek, p. 602.* We discuss the relation between some early techniques for constrained channel coding and more recent ones adapted from the mathematical area of symbolic dynamics. A primary difference between the two is that the latter focus on issues of code existence, whereas the former were primarily concerned with code construction and optimality.

Matrix print actuator for dot band printer *by J. L. Zable and E. F. Helinski, p. 609.* The design selection of an impact matrix print actuator is described, along with its method of design and optimization. The dot band printer concept is discussed in conjunction with operational requirements for the hammer; these requirements, and methods of meeting them, are presented.

Preserving the integrity of cyclic-redundancy checks when protected text is intentionally altered *by D. R. Irvin, p. 618.* As a digitally encoded message traverses a series of point-to-point communication links, it may be necessary to change the contents of that message at an intermediate station. If bit errors are introduced by the intermediary while the text is unprotected, these errors will be subsequently undetectable by cyclic redundancy checks. An algorithm is presented here for ensuring that such errors will not go undetected. Since the cyclic redundancy check is based on a linear mathematical operation, the frame-check sequence may be modified, rather than recalculated, by each intermediary changing the protected text. A frame-check sequence constructed in this way will reveal any errors introduced in the transmission path when the message is finally examined at the ultimate destination. Examples of the proposed technique applied to various local-area network bridges are developed. The technique is shown to be beneficial in these examples when the internal bit-error ratio of the text-changing device exceeds 10^{-19} on unprotected paths.

Representing knowledge with functions and Boolean arrays *by K. Fordyce, J. Jantzen, G. A. Sullivan, Sr., and G. A. Sullivan, Jr., p. 627.* Over the past eighteen years a variety of advanced decision support systems have been built with knowledge-based expert system (KBES) components. For the past eight years, a knowledge representation and manipulation (KRM) scheme called FABA (Functions And Boolean Arrays) has been used. It has two basic principles. First, knowledge is viewed as a functional mapping between input and output variables, where the functions are expressed as *fact tables* or *bases* and *procedure modules.* Second, the function network can be represented with Boolean arrays. The basics of FABA, its implementation in APL2, and a simple example of FABA's application in a manufacturing dispatch application for IBM's semiconductor facility in Burlington, Vermont, are described in this paper.

Fault-simulation programs for integrated-circuit yield estimations *by C. H. Stapper, p. 647.* Three programs are described here which have been used for integrated-circuit yield modeling at the IBM facility in Essex Junction, Vermont. The first program generates negative binomial distributions which are used to represent the frequency distribution of the number of faults per chip. Calculations with the generalized combination function *A ! B* in *APL* are limited to simulations of up to 99,999 faults, and can take too much computer time to run. These limitations are eliminated when the calculations make use of the scan function. The second program simulates clustered fault locations on a map. The clusters are initially generated using a radial Gaussian probability distribution. Each fault location is stored as a complex number, which facilitates the use of cluster-shaping programs that are also described. In a third program, another simulator of fault maps, faults are added as a function of time. This program also results in fault distributions that are clustered. In addition, it produces frequency distributions that very closely approximate negative binomial distributions.

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Preface *by N. M. Donofrio, p. 2.*

The evolution of RISC technology at IBM *by J. Cocke and V. Markstein, p. 4.* This paper traces the evolution of IBM RISC architecture from its origins in the 1970s at the IBM Thomas J. Watson Research Center to the present-day IBM RISC System/6000® computer. The acronym RISC, for Reduced Instruction-Set Computer, is used in this paper to describe the 801 and subsequent architectures. However, RISC in this context does not strictly imply a reduced number of instructions, but rather a set of primitives carefully chosen to exploit the fastest component of the storage hierarchy and provide instructions that can be generated easily by compilers. We describe how these goals were embodied in the 801 architecture and how they have since evolved on the basis of experience and new technologies. The effect of this evolution is illustrated with the results of several benchmark tests of CPU performance.

The IBM RISC System/6000 processor: Hardware overview *by H. B. Bakoglu, G. F. Grohoski, and R. K. Montoye, p. 12.* A highly concurrent superscalar second-generation family of RISC workstations and servers is described. The RISC System/6000® family is based on the new IBM POWER (Performance Optimization With Enhanced RISC) architecture; the hardware implementation takes advantage of this powerful RISC architecture and employs sophisticated design techniques to achieve a short cycle time and a low cycles-per-instruction (CPI) ratio. The RS/6000 CPU features multiple-instruction dispatch, multiple functional units that operate concurrently, separate instruction and data caches, and zero-cycle branches. In this superscalar implementation, at a given cycle the equivalent of five operations can be executed simultaneously (a branch, a condition-register operation, and a floating-point multiple-add). The RS/6000 family supports the IBM Micro Channel architecture as well as high-speed serial optical links to provide a high-bandwidth I/O subsystem.

IBM RISC System/6000 processor architecture *by R. R. Oehler and R. D. Groves, p. 23.* This paper describes the hardware architecture of the IBM RISC System/6000® processor, which combines basic RISC principles with a partitioning of registers by function into multiple ALUs. This allows a high degree of parallelism in execution and permits a compiler to generate highly optimized code to manage the interaction among parallel functions. Floating-point arithmetic is integrated into the architecture, and floating-point performance is comparable to that of many vector processors.

Machine organization of the IBM RISC System/6000 processor *by G. F. Grohoski, p. 37.* The IBM RISC System/6000® processor is a second-generation RISC processor which reduces the execution pipeline penalties caused by branch instructions and also provides high floating-point performance. It employs multiple functional units which operate concurrently to maximize the instruction execution rate. By employing these advanced machine-organization techniques, it can execute up to four instructions simultaneously. Approximately 11 MFLOPS are achieved on the LINPACK benchmarks.

Design of the IBM RISC System/6000 floating-point execution unit *by R. K. Montoye, E. Hokenek, and S. L. Runyon, p. 59.* The IBM RISC System/6000® (RS/6000) floating-point unit (FPU) exemplifies a second-generation RISC CPU architecture and an implementation which greatly increases floating-point performance and accuracy. The key feature of the FPU is a unified floating-point multiply-add-fused unit (MAF) which performs the accumulate operation $(A \times B) + C$ as an indivisible operation. This single functional unit reduces the latency for chained floating-point operations, as well as rounding errors and chip busing. It also reduces the number of adders/normalizers by combining the addition required for fast multiplication with accumulation. The MAF unit is made practical by a unique fast-shifter, which eases the overlap of multiplication and addition, and a leading-zero/one anticipator, which eases overlap of normalization and addition. The accumulate instruction required by this architecture reduces the instruction path length by combining two instructions into one. Additionally, the RS/6000 FPU is tightly coupled to the rest of the CPU, unlike typical floating-point coprocessor chips. As a result, floating-point and fixed-point instructions can be executed simultaneously. Load/store operations are performed using register renaming and store buffering to allow completely independent operation of load/store with arithmetic operations. Thus, data-cache accesses can occur in parallel with independent arithmetic operations. This unit attains a peak execution rate of 50 MFLOPS with a 25-MHz clock frequency and is capable of sustaining nearly that rate in complex programs such as graphics and Livermore loops.

Leading-zero anticipator (LZA) in the IBM RISC System/6000 floating-point execution unit *by E. Hokenek and R. K. Montoye, p. 71.* This paper presents a novel technique used in the multiply-add-fused (MAF) unit of the IBM RISC System/6000® (RS/6000) processor for normalizing the floating-point results. Unlike the conventional procedures applied thus far, the so-called leading-zero anticipator (LZA) of the RS/6000 carries out processing of the leading zeros and ones in parallel with floating-point addition. Therefore, the new circuitry reduces the total latency of the MAF unit by enabling the normalization and addition to take place in a single cycle.

Pseudorandom built-in self-test methodology and implementation for the IBM RISC System/6000 processor *by I. M. Ratiu and H. B. Bakoglu, p. 78.* This paper describes a unified self-test and system bring-up methodology. The components involved include a common on-chip processor (COP) that executes the chip self-test sequence and provides

an interface to the COP bus, a serial bus (COP bus) that links the chips to OCS and ESP, an on-card sequencer (OCS) that controls the self-test and system initialization sequences, and an engineering support processor (ESP) that is used for system verification, bring-up, and debug. Almost all RISC System/6000® chips contain embedded RAMs such as register files, caches, and directories; therefore, the self-test methodology described here is particularly suitable for logic chips that contain embedded arrays. Logic and RAM self-test is executed by a control processor (COP) integrated on the chips. The COP controls the self-test sequence, generates pseudorandom test vectors, scans them into chip registers, and provides the select lines that establish a one-to-one correspondence between RAM input/output and chip registers. The COP also drives RAM read/write lines during self-test, scans the captured RAM outputs, and compresses them to obtain a signature. After the vectors are scanned in, the chip runs for one or two system cycles, the logic outputs are captured in registers, and the chip state is scanned back into the COP, where it is compressed to obtain a signature. This procedure is repeated many times, and the final signature is then compared with a predetermined "good" signature to establish whether the chip is good or bad. Special techniques are developed to improve the coverage of logic that feeds RAMS or receives its inputs from RAMs. Both ac and dc self-test are described. The self-test sequence is controlled by a program stored in the OCS, and ESP is used during system bring-up to set up break-points and to display and modify the machine state.

Instruction scheduling for the IBM RISC System/6000 processor *by H. S. Warren, Jr., p. 85.* For fast execution on the IBM RISC System/6000® processor, instructions should be arranged in an order that uses the arithmetic units as efficiently as possible. This paper describes the scheduling requirements of the machine, and a scheduling algorithm for it that is used in two compilers.

Instruction scheduling beyond basic blocks *by M. C. Golumbic and V. Rainish, p. 93.* Instruction scheduling consists of the rearrangement or transformation of program statements, usually at the intermediate language or assembly code level, in order to reduce possible run-time delays between instructions. Such transformations must preserve data dependency and are subject to other constraints. Highly optimizing compilers employing instruction-scheduling techniques have proven to be effective in improving the performance of pipeline processors. Considerable attention has been given to scheduling code within the scope of basic blocks, i.e., straight-line sections of code. In this paper we present techniques for scheduling beyond basic blocks. This allows a further reduction in run-time delays such as those due, e.g., to branches and loops, enabling the exploiting of pipeline architectures which would not otherwise be possible.

Managing programs and libraries in AIX Version 3 for RISC System/6000 processors *by M. A. Auslander, p. 98.* This paper describes the program and program-library management facility that has been developed for the AIX® operating system, Version 3, as implemented for the IBM POWER (Performance Optimization With Enhanced RISC) architecture. It provides run-time loading of libraries, symbol resolution with type checking, and relocation. In addition, the use of the loader to add programs to an already running process or to the kernel is offered. The advantages of these functions and the techniques needed to provide a usable and efficient realization are described. Particular attention is given to the special problems posed by very large programs, and by very small programs which use services from very large libraries.

Evolution of storage facilities in AIX Version 3 for RISC System/6000 processors *by A. Chang, M. F. Mergen, R. K. Rader, J. A. Roberts, and S. L. Porter, p. 105.* The AIX® Version 3 storage facilities include features not found in other implementations of the UNIX® operating system. Maximum virtual memory is more than 1000 terabytes and is used pervasively to access all files and the meta-data of the file systems. Each separate file system (subtree) of the file name hierarchy occupies a logical disk volume, composed of space from possibly several disks. Database memory (a variant of virtual memory) and other database techniques are used to manage file system meta-data. These features provide the capacity to address large applications and many users, simplified program access to file data, efficient file buffering in memory, flexible management of disk space, and reliable file systems with short restart times.

Computation of elementary functions on the IBM RISC System/6000 processor *by P. W. Markstein, p. 111.* The additional speed and precision of the IBM RISC System/6000® floating-point unit have motivated reexamination of algorithms to perform division, square root, and the elementary functions. New results are obtained which avoid the necessity of doing special testing to get the last bit rounded correctly in accordance with all of the IEEE rounding modes in the case of division and square root. For the elementary function library, a technique is described for always getting the last bit rounded correctly in the selected IEEE rounding mode.

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Preface *by P. G. May, p. 139.*

Electro-optic sampling of high-speed devices and integrated circuits *by J. M. Wiesenfeld, p. 141.* The operating speeds of the fastest electronic devices and integrated circuits (ICs) have surpassed the capabilities of conventional electronic measurement instrumentation. Electro-optic sampling is an optical probing technique which has ultrashort temporal resolution and is capable of noninvasively probing ICs at internal nodes. This technique is voltage-sensitive because it relies upon the electric field produced by the signal

voltage on the device under test (DUT). The electric field (and hence the voltage) can be sampled because it produces birefringence in an electro-optic crystal which changes the state of polarization of an ultrashort-duration optical probe pulse that propagates through the electro-optic crystal. The electro-optic crystal is the substrate of the DUT for direct probing, is a crystal on a separate test structure for hybrid probing, and is a separate crystal placed above the DUT for external probing. Temporal resolution below 1 ps and a sensitivity below 0.1 mV/$\sqrt{\text{Hz}}$ have been demonstrated (though not in the same experiment). The principles of electro-optic sampling are reviewed in this paper. Selected applications for measurement of high-speed waveforms in discrete devices and in ICs are presented.

Picosecond noninvasive optical detection of internal electrical signals in flip-chip-mounted silicon integrated circuits *by H. K. Heinrich, p. 162.* This paper reviews the charge-sensing optical probing system, and shows how it may be used to detect internal current and voltage signals in flip-chip-mounted silicon integrated circuits. Previously, researchers have used this concept to detect both single-shot 200-MHz-bandwidth signals, without averaging, and 8-GHz-bandwidth stroboscopic signals. This system has a high sensitivity: 145-nA/$\sqrt{\text{Hz}}$ current sensitivity in typical bipolar transistors, and 1.35-mV/$\sqrt{\text{Hz}}$ voltage sensitivity in typical CMOS circuits (using a semiconductor laser probe). It is noninvasive, has a potential submicron spatial resolution, and should be capable of providing linear and calibrated measurements. Therefore, this probing approach should be a powerful tool for future circuit analysis and testing.

Picosecond photoemission probing of integrated circuits: Capabilities, limitations, and applications *by R. Clauberg, H. Beha, A. Blacha, and H. K. Seitz, p. 173.* The capabilities and limitations of the novel photoemission probing technique for signal measurements on internal nodes of VLSI integrated circuits are reviewed with respect to the range of possible applications of this method. Aspects such as voltage sensitivity, time resolution, minimum accessible feature size, sensitivity to perturbation effects, and impact on the circuit under test are considered. It is concluded that the especially high voltage sensitivity of this new method opens the field of diagnostics of circuits with ultrafast devices but partly low signal repetition rates, which is not accessible by other means. Such chips include, for example, complex logic chips and special telecommunication chips.

Flexible picosecond probing of integrated circuits with chopped electron beams *by D. Winkler, R. Schmitt, M. Brunner, and B. Lischke, p. 189.* The effective design and evaluation of high-speed integrated circuits is supported by internal noninvasive voltage-measurement techniques with picosecond time resolution. An electron-beam tester has therefore been developed which approaches the theoretical time-resolution limit of this method. It is based on the well-established e-beam technique for VLSI circuits, allowing for high flexibility in driving different kinds of high-frequency circuits under both conventional and critical conditions. The electron pulses of the stroboscopic test system are generated by a two-stage chopping system which was optimized to obtain very short pulses. It allows for a 7-ps effective pulse width which simultaneously yields a probe diameter of 0.5 μm and a probe current of 1 nA. This current results in a noise voltage of 20 mV when one period of a 1-GHz signal is recorded, with a total acquisition time of 0.1 s. Long-range phase shifting with high resolution is achieved by operating the upper stage of the blanking system at a high frequency and using the lower one as a selective gate. This allows propagation-delay measurements to be performed with a resolution of better than 2 ps over a range of several μs. The test system has thus far been used for that analysis of tunnel diodes, step-recovery diodes, bipolar frequency dividers, ring oscillators, and GaAs memories. Waveform measurement and evaluation at more than 60 different test points of a GaAs 1-kb SRAM in a six-hour session has demonstrated routine handling of complex high-speed circuit analysis.

Picosecond photoelectron microscope for high-speed testing of integrated circuits *by P. May, Y. Pastol, J.-M. Halbout, and G. Chiu, p. 204.* The performance of devices an circuits is advancing at a rapid pace with the advent of submicron design ground rules and switching times under 50 ps. The requirements for probing the internal nodes of these ultra-fast, -small, and -dense circuits give rise to great challenges for high-speed electron-beam testing. In this paper, we review the steps which have allowed electron-beam testing to achieve simultaneously 5-ps temporal resolution, 0.1-μm spot size, and 3 mV/$\sqrt{\text{Hz}}$ voltage sensitivity. The resulting newly developed instrument, called the picosecond photoelectron scanning electron microscope (PPSEM), is capable of measuring the state-of-the-art bipolar and FET circuits and also VLSI passive interconnects.

A submicron electron-beam tester for VLSI circuits beyond the 4-Mb DRAM *by F. Fox, J. Kölzer, J. Otto, and E. Plies, p. 215.* This paper describes the electron-optical low-voltage column of the submicron electron-beam tester. It can be used to produce an electron probe of 0.12-μm diameter, 2.5-nA probe current, and 1-kV beam voltage. It is shown that in the case of waveform measurements on 1.1-μm interconnection lines, the crosstalk is only ~ 3%. The voltage resolution is sufficient to allow the sense signal of a 4-Mb DRAM (dynamic random access memory) to be measured. Further internal measurements with the electron probe for the chip verification of the 4-Mb DRAM are also shown which demonstrate the flexibility and the benefits of electron-beam testing. On the basis of the measured performance data and its successful use in the circuit analysis of the 4-Mb DRAM, the submicron electron-beam tester appears to be suitable also for VLSI circuits with reduced design rules, e.g., for the 16-Mb DRAM. The improvements required for such future applications are briefly discussed.

Internal probing of submicron FETs and photoemission using individual oxide traps *by P. Restle and A. Gnudi, p. 227.* In submicron field-effect transistors with channel area less than 0.5 μm^2, the capture or emission of a single electron (or hole) in the gate oxide has an easily observable effect on the device resistance. Measurements are described in which the time and amplitude of the resistance change due to each capture and emission event from an individual trap are extracted to obtain the average capture and emission times, and the amplitude of the resistance change, at different temperatures, device biases, and light intensities. Techniques are described for using the data at different biases to characterize the trap, find the location of the trap in the device, and then use the trap as a probe of the oxide field (or surface potential) and the surface charge density within a 5–50-Å radius of the trap. In some devices a single trap can be resolved over almost all designed bias regions of the FET near room temperature. In effect, individual traps can be used as internal probes into VLSI devices of the present and future. Results from 2D computer device modeling of these devices are used to evaluate and understand these techniques. Methods for applying these techniques to the study of device degradation are discussed. Data are presented in which photoemission is observed from a single electron trap.

A submicron MOSFET parameter extraction technique *by B. El-Kareh, W. R. Tonti, and S. L. Titcomb, p. 243.* A technique is introduced for measuring electron and hole mobilities as a function of temperature and normal field in inverted silicon surfaces. We also introduce a new definition of threshold voltage which allows the method to measure mobility independent of channel dimensions and resistance in series with the channel. The results are used to extract the resistance in series with the channel, the effective channel dimensions, and the intrinsic MOSFET transconductance. The technique is demonstrated on MOSFETs with channel lengths ranging from 0.25 μm to 20 μm.

Electron-beam technology for open/short testing of multi-chip substrates *by S. D. Golladay, N. A. Wagner, J. R. Rudert, and R. N. Schmidt, p. 250.* We discuss the need for noncontact electrical testing of high-performance multi-chip substrates and describe an electron-beam tester developed for this application. We describe the operational principles of the tester and compare and contrast its performance with that of mechanical probe testers. Finally, we discuss the motivations and technical issues involved in extending the electron-beam test method to future high-performance packages.

The development of ultra-high-frequency VLSI device test systems *by C. W. Rodriguez and D. E. Hoffman, p. 260.* The development of test systems for high-performance semiconductor logic and memory devices is discussed. The capabilities of shared-resource and tester-per-pin system architectures are reviewed. Test-system hardware design to provide high-speed pin electronics and generation of LSSD, weighed random, and algorithmic patterns is described. The reasons for the selection of the tester-per-pin system architecture are given in terms of the way in which overall system accuracy and test-system user flexibility are maximized for differing test methodologies.

Test generation for VLSI chips with embedded memories *by E. K. Vida-Torku, J. A. Monzel, T. L. Bossis, C. E. Radke, and D. M. Wu, p. 276.* An effective approach for generating patterns for testing memories embedded in logic is presented. Through circuit testability analysis, which is a study of the effect of process defects on memory circuits, unique algorithms can be derived for testing the memory. Circuit and logic designs for test features that are required to make the pattern generation process optimal are discussed. An analytical method is described which assesses the performance characteristics of the memory after functional test.

Simulation of embedded memories by defective hashing *by L. M. Huisman, p. 289.* Because logic designs are becoming more complex and extensive, they increasingly tend to contain embedded memories. In the simulation (particularly fault simulation) of these designs, the embedded memories may be found to require large amounts of storage unless a carefully designed simulation strategy is adopted. This paper describes a technique that drastically reduces the storage required in the fault simulation of such large designs. The required amount of storage can be fixed at compile time or at load time, and can almost always be made to fit in the available storage at the cost of only a small decrease in the predicted exposure probabilities.

A logic chip delay-test method based on system timing *by F. Motika, N. N. Tendolkar, C. C. Beh, W. R. Heller, C. E. Radke, and P. J. Nigh, p. 299.* In this paper we present a novel approach to delay-testing of VLSI logic chips based on the level-sensitive scan design (LSSD) methodology. The objective of the delay test is to reduce significantly the failures of multi-chip modules at system integration test while minimizing the complexity and cost of subassembly testing. Because system timing data are used to derive test specifications, the delay defects that are most likely to cause a system path failure are detected a high percentage of the time. With the implementation of the delay test in the wafer production line, the system final-test failure rate of multi-chip modules used in IBM mainframe machines has dropped significantly.

An ac test structure for fast memory arrays *by R. C. Wong, p. 314.* An ac test structure (ACTS) built into fast memory arrays is required to make them truly ac-testable, with 5–10% timing accuracy. Since their ac performance is very difficult to characterize, wafer tester timing uncertainty is generally about 10–50% of a typical array access time. More accurate testers are complex and expensive; they require long development time and have complicated operation procedures. ACTS is a simpler, cheaper, and more practical means of achieving greater accuracy. An ac test structure is composed

of a tunable timer and path-shifting oscillators (PSOs) built around the various access paths of the array. The timer generates the array clocks with adjustable pulse widths, and the PSOs transform time intervals into frequencies. In the future, tester accuracy will improve, but memory performance will have accelerated even more. Thus, the need for ACTS is critical and will remain so in the foreseeable future.

Gross delay defect evaluation for a CMOS logic design system product *by O. Bula, J. Moser, J. Trinko, M. Weissman, and F. Woytowich, p. 325.* Randomly occurring gross delay defects allow chips to pass full stuck-fault testing at both wafer and module levels, but cause them to fail when operated at system speeds. This paper describes the results of an experiment designed to determine the actual delay defect component of shipped product quality level (SPQL) for a CMOS combination standard cell/gate array design system. More than 60,000 modules, representing chips from the same IBM computer system, have been delay-tested using the technique presented in this paper. The test technique uses the stuck-fault patterns for level-sensitive scan design (LSSD) product. The stuck-fault patterns are modified or "twisted" according to specific algorithms to propagate transitions through paths just prior to the output measure. The patterns are applied at system speed timings provided by the chip designers. Any gross delay defect present in a tested path causes a fail. The failing modules were characterized to determine the size of the delay defects. Failure diagnostics were performed on the defective modules by using existing stuck-fault diagnostic tools and a development version of a transition fault simulator. These were sent to physical failure analysis for delayering, visual verification, and electrical characterization. A summary of physical defects which produced gross delay defects is presented.

Boundary-scan design principles for efficient LSSD ASIC testing *by R. W. Bassett, M. E. Turner, J. H. Panner, P. S. Gillis, S. F. Oakland, and D. W. Stout, p. 339.* A boundary-scan logic design method that depends only on level-sensitive scan design (LSSD) principles has been developed for IBM CMOS application-specific integrated circuit (ASIC) products. This technique permits comprehensive testing of LSSD ASICs with high signal input/output (I/O) pin counts, using relatively inexpensive reduced-pin-count automatic test equipment (ATE). This paper describes the LSSD logic structures required, the reduced-pin-count testing and burn-in processes used, and the ASIC product design decisions that must be made to establish a consistent boundary-scan implementation.

Design for testability and diagnosis in a VLSI CMOS System/370 processor *by C. W. Starke, p. 355.* This paper describes the design for testability and diagnosis in an IBM System/370 processor based on VLSI CMOS technology. The design incorporates built-in pseudorandom-pattern self-test and the boundary-scan technique. This technique permits the migration of tests generated for component-level to higher-level packages such as printed circuit boards and the system. Consequently, the expense for testing of higher-level packages can be reduced, and the test equipment for the processor can be simplified. The design also offers economical diagnostic capability.

Aliasing errors in linear automata used as multiple-input signature analyzers *by W. Daehn, T. W. Williams, and K. D. Wagner, p. 363.* This paper deals with the aliasing probability of multiple-input data compressors used in self-testing networks. It is shown that a far more general class of linear machines than linear feedback shift registers can be used for data compression purposes. The function of these machines is modeled by a Markov process. The steady-state value of the aliasing probability is shown to be the same as for single-input signature analysis registers. An easily verifiable criterion is given that allows one to decide whether a given linear machine falls into this class of multiple-input data compressors. The steady-state value of the aliasing probability is shown to be independent of the correlation of the data streams at the inputs of the data compressor. Two kinds of circuits are analyzed in more detail with respect to their aliasing properties: linear feedback shift registers with multiple inputs, and linear cellular automata. Simulation results show the effect of the next-state function on the steady-state value of the aliasing probability and the effect of correlation on the transient response.

Improved cutting algorithm *by J. Savir, p. 381.* The cutting algorithm allows computation of bounds on signal probabilities and detection probabilities in combinational networks. These bounds can be used to determine the necessary pseudorandom test length needed to test a network. One of the problems with the cutting algorithm is that it may compute loose bounds which translate into unnecessarily long test lengths. The object of this paper is to improve the cutting algorithm so that the computed bounds become satisfactory. The improved cutting algorithm is a careful combination of the original cutting algorithm and the Parker–McCluskey algorithm. The tightness of the computed bounds may vary depending on which portion of the circuit is handled with the cutting algorithm and which with the Parker–McCluskey algorithm. Thus, the user of the improved cutting algorithm can actually control and trade off the accuracy of the results against the computational effort needed to achieve them.

Cellular automata circuits for built-in self-test *by P. D. Hortensius, R. D. McLeod, and B. W. Podaima, p. 389.* Results are presented for a variation on a built-in self-test (BIST) technique based upon a distributed pseudorandom number generator derived from a one-dimensional cellular automata (CA) array. These cellular automata logic block observation (CALBO) circuits provide an alternative to conventional design for testability circuitry such as built-in logic block observation (BILBO) as a direct consequence of reduced cross-correlation between the bit streams which are used as inputs to the logic unit under test. The issue of

generating probabilistically weighted test patterns for use in built-in self test is also addressed. The methodology presented considers the suitability of incorporating structures based on cellular automata, a strategy which, in general, improves test pattern quality. Thus, CA-based structures quality as attractive candidates for use in weighted test pattern generator design. The analysis involved in determining and statistically evaluating these potential models is discussed, and is compared with that for previous as well as statistically independent models. Relevant signature analysis properties for elementary one-dimensional cellular automata are also discussed. It is found that cellular automata with cyclic-group rules provide signature analysis properties comparable to those of the linear feedback shift register. The results presented here are based upon simulation.

Built-in self-test support in the IBM Engineering Design System *by B. L. Keller and T. J. Snethen, p. 406.* To evaluate the effectiveness of built-in self-test (BIST) for logic circuits, the test design automation (TDA) group within the IBM Engineering Design System (EDS) has developed tools to support BIST. This paper is an overview of that support. The specific hardware approaches taken are described briefly, and a short description is given of the major tools that have been developed and the methodology for using them. The performance of the system is shown for two sample circuits.

Self-testing the 16-Mbps adapter chip for the IBM token-ring local area network *by S. F. Oakland, J. L. Corr, J. D. Blair, V. R. Norman, and W. J. DeGuise, p. 416.* This paper describes the boundary-scan and built-in self-test (BIST) functions of the IBM token-ring local area network (LAN) adapter chip. These functions present a number of unique features. First, less that 1% of available standard cell circuits were needed to implement these functions. Second, clocking methods used in different logical macros were merged into a comprehensive clocking sequence for self-test. Finally, asynchronous serial and parallel interfaces were provided to facilitate the communication between a test system and the chip's built-in test circuits. Although self-test and boundary-scan provide for an inexpensive higher-level package test, evaluation showed that automatically generated deterministic patterns provide a better-quality VLSI chip manufacturing test.

LAN interface chip and mixed-signal testing developments *by J. J. Van Horn, R. A. Waller, R. J. Prilik, and K. C. Bocash, p. 428.* This paper describes the local area network (LAN) semiconductor chip, from early development through volume manufacturing production, highlighting the testing achievements associated with its qualification and release to production. The paper is divided into two sections dealing with laboratory development and production in manufacturing. The development section describes the importance of partitioning via latch-based boundaries, and how it reduced development cycle time by allowing independent debug and diagnostic tests. The development of tests to characterize the phase-lock loop (PLL) at application conditions and the evolution of these tests into efficient production test vehicles are discussed. Techniques are described that provide new approaches to analog testing, focusing on adapting a production digital tester to meet the characterization and production requirements of a very sensitive PLL/receiver/transmitter analog design. The manufacturing discussion is centered around three areas, wafer testing, yield learning, and reliability. Unique concepts in each area are presented, along with detailed descriptions of specific applications.

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Preface *by M. Heiblum and S. S. Iyer, p. 450.*

Experimental technology and performance of 0.1-μm-gate-length FETs operated at liquid-nitrogen temperature *by G. A. Sai-Halasz, M. R. Wordeman, D. P. Kern, S. A. Rishton, E. Ganin, T. H. P. Chang, and R. H. Dennard, p. 452.* An overview is presented of our work to explore the extendibility of the silicon FET technology to the 0.1-μm-gate-length level. Self-aligned, *n*-channel, polysilicon-gated FETs were designed for operation at 77K, with reduced power-supply voltage. Direct-write electron-beam lithography was used to pattern all levels, while other processing followed established lines. Noteworthy results of the work included the observation of a clear manifestation of velocity overshoot, which contributed to achieving extrinsic transconductances above 940 μS/μm at 0.07-μm gate length. The measured switching delay of ring oscillators which contained 0.1-μm-gate-length devices was as low as 13.1 ps, with simulations showing potential for reduction to below 5 ps. Both the transconductance and the switching times are the best values observed for FETs to date—indicating continuing value in the scaling of FETs to dimensions well beyond those currently used.

Monte Carlo analysis of semiconductor devices: The DAMOCLES program *by S. E. Laux, M. V. Fischetti, and D. J. Frank, p. 466.* The behavior of small semiconductor devices is simulated using an advanced Monte Carlo carrier transport model. The model improves upon the state of the art by including the full band structure of the semiconductor, by using scattering rates computed consistently with the band structure, and by accounting for both long- and short-range interactions between carriers. It is sufficiently flexible to describe both unipolar and bipolar device operation, for a variety of semiconductor materials and device structures. Various results obtained with the associated DAMOCLES program for *n*- and *p*-channel Si MOSFETs, GaAs MESFETs, and Si bipolar junction transistors are presented.

Submicron-gate-length GaAs MESFETs *by T. N. Jackson, B. J. Van Zeghbroeck, G. Pepper, J. F. DeGelormo, T. Keuch, H. Meier, and P. Wolf, p. 495.* It is well known that reducing gate length is a powerful means to increase the

transconductance and transit frequency of GaAs MESFET devices. However, by reducing the gate length without scaling channel doping and thickness, the performance obtained is limited by short-channel effects and parasitics. In this paper we present an overview of our work on two different MESFET structures, illustrating how device performance can be increased by decreasing the gate length, with the result that appropriately scaled MESFETs compare favorably with GaAs–AlGaAs heterojunction FETs. From our work—including some recent results on 0.15-μm-gate-length implantation-self-aligned MESFETs—we conclude that it should be possible to increase the speed of high-speed GaAs MESFET (logic, analog, and microwave) circuits through the use of devices having gate lengths less than 0.5 μm.

Heterojunction FETs in III–V compounds *by R. A. Kiehl, P. M. Solomon, and D. J. Frank, p. 506.* We review work on heterojunction FETs (HFETs) fabricated from III–V compounds, with emphasis on the unique properties of such devices and their applicability to high-speed logic circuits. After discussing their general properties, including their uniquely high carrier mobility and fast switching speed, we discuss HFETs investigated at the IBM Thomas J. Watson Research Center, i.e., the semiconductor–insulator–semiconductor FET (SISFET) and quantum-well metal–insulator–semiconductor FET (QW-MISFET)—and their possible circuit applications. Finally, the opportunities for achieving a circuit performance level beyond that offered by the GaAs–(Al,Ga)As materials system are explored.

Ballistic hot-electron transistors *by M. Heiblum and M. V. Fischetti, p. 530.* We present an overview of work at the IBM Thomas J. Watson Research Center on the tunneling hot-electron transfer amplifier (THETA) device—including its use as an amplifier and as a tool for investigating ballistic hot-electron transport. In the initial, vertically configured version of the device, a quasi-monoenergetic, variable-energy, hot-electron beam is generated (via tunneling) which traverses a thin GaAs region and is then collected and energy-analyzed. As the hot electrons traverse the device, they are used to probe scattering events, band nonparabolicity, size-quantization effects, and intervalley transfer. A recent, lateral version of the device has been used to demonstrate the existence of ballistic hot-electron transport in the plane of a two-dimensional electron gas, and the associated possibility of achieving high gain.

Compound semiconductor heterostructure bipolar transistors *by S. Tiwari, S. L. Wright, and D. J. Frank, p. 550.* This paper is primarily an overview of our work on the technology, material and electronic properties, and performance limitations of compound semiconductor heterostructure bipolar transistors. Graded-gap epitaxial *n*-type ohmic contacts and *p*-type shallow diffusion ohmic contacts are important in the fabrication of high-performance (Al,Ga)As/GaAs devices. In the device structure implemented, the presence of a wide-gap *p*-type (Al,Ga)As extrinsic base region at the surface suppresses surface recombination, thereby enhancing the current gain at small device dimensions. We discuss experimental and theoretical results concerning the limiting physical effects due to heterostructure design and intrinsic and extrinsic bulk phenomena of compound semiconductors, emphasizing the understanding developed and the discoveries made during the course of our efforts. As device speeds have increased with coordinated scaling, dispersive effects have become increasingly important. We show how these may be included by modifying the conventional quasi-static modeling of the bipolar transistor, in order to obtain a realistic simulation of fast switching transients. Finally, we discuss scaling of heterostructure bipolar transistors, and implications of the use of lower-bandgap materials and operation at cryogenic temperatures.

High-speed GaAs/AlGaAs optoelectronic devices for computer applications *by C. S. Harder, B. J. Van Zeghbroeck, M. P. Kesler, H. P. Meier, P. Vettiger, D. J. Webb, and P. Wolf, p. 568.* We present an overview, mainly of work in our laboratory, of low-threshold GaAs/AlGaAs quantum-well laser diodes and GaAs metal–semiconductor–metal photodetectors—two optoelectronic devices which show good promise for use in computer-related communication. Present-day telecommunication device technology (based on InP materials) is not well suited to the requirements of optical data communication among and within computers because the computer environment is much more demanding. It imposes a higher ambient temperature on the devices, and requires denser packaging and smaller power dissipation per device, as well as a high degree of parallelism. The GaAs/AlGaAs device technology is ideally suited to this task because of the possibility of integration of arrays of high-speed, low-threshold laser diodes and high-speed photodetectors with high-performance electronic circuits.

An electromagnetic approach for modeling high-performance computer packages *by B. J. Rubin, p. 585.* Described here is an electromagnetic approach for the analysis of high-performance computer packages such as the thermal conduction module (TCM) used in the IBM 3080 and 3090 processor units. Modeling of signal paths and limitations of previous methods are discussed. Numerical results are presented for propagation characteristics associated with signal lines and vias, and for coupled noise between signal lines. The results are compared with those obtained by means of test vehicles, scale models, and capacitance calculations.

High-speed signal propagation on lossy transmission lines *by A. Deutsch, G. V. Kopcsay, V. A. Ranieri, J. K. Cataldo, E. A. Galligan, W. S. Graham, R. P. McGouey, S. L. Nunes, J. R. Paraszczak, J. J. Ritsko, R. J. Serino, D. Y. Shih, and J. S. Wilczynski, p. 601.* This paper addresses some of the problems

encountered in propagating high-speed signals on lossy transmission lines encountered in high-performance computers. A technique is described for including frequency-dependent losses, such as skin effect and dielectric dispersion, in transmission line analyses. The disjoint group of available tools is brought together, and their relevance to the propagation of high-speed pulses in digital circuit applications is explained. Guidelines are given for different interconnection technologies to indicate where the onset of severe dispersion takes place. Experimental structures have been built and tested, and this paper reports on their electrical performance and demonstrates the agreement between measured data and waveforms derived from analysis. The paper addresses the problems found on lossy lines, such as reflections, rise-time slowdown, increased delay, attenuation, and crosstalk, and suggests methods for controlling these effects in order to maintain distortion-free propagation of high-speed signals.

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Preface *by M. A. Wesley, p. 634.*

A modeling system for top-down design of assembled products *by M. Mäntylä, p. 636.* The design of a mechanical product usually takes place primarily in a top-down fashion, where the designer first generates a rough, overall sketch of the product and its main components. Later, the designer refines the sketch to a detailed level while taking into account the relevant requirements posed by strength, cost, manufacturability, serviceability, and other similar considerations. Current computer-aided design (CAD) systems provide only limited support for this kind of work. For instance, they cannot deal with geometric or other information at varying levels of detail, nor do they capture explicitly geometric relationships among components intended to be joined together in an assembly. This paper describes early results of ongoing research on supporting top-down design of mechanical products and discusses the major requirements for CAD systems used for top-down design. A prototype design system is described that provides the following characteristics not usually found in ordinary CAD systems: structuring of product information in several layers, according to the stage of the design process; representation of geometric information about components at several levels of detail; and representation and maintenance of geometric relationships of components by means of a constraint-satisfaction mechanism.

Computer-aided design of slider bearings in magnetic disk files *by K. L. Deckert, p. 660.* This paper reviews the application of lubrication theory to slider bearings in magnetic disk files. For more than thirty years, slider bearings have been used to maintain close and precise spacings between recording transducer and recording medium in disk files. Computer modeling has been central to the design and performance analysis of these systems. The topics covered are the basic design, sensitivity and tolerance analysis, dynamic characteristics, and response to disk excitations from the disk. The main purpose of this paper is to review the use of computer modeling in design of slider bearings; however, the discussion of slider modes in the slider dynamics section is new.

Disk file access-time constraints imposed by magnetic air-bearing compliance *by E. S. Cooper, p. 668.* Use is commonly made of coil voltages which produce maximum acceleration and deceleration to wrest the fastest access performance from the actuator of a disk file. Alternatively, equivalent performance is easily obtained with less control optimality by simply increasing the coil voltage. A limit to greater coil voltage, however, arises from the need to avoid harmful effects when the servo loses control of the actuator, the actuator slams into its crash stop, and the crash force stresses the magnetic head air bearing. Magnetic head air-bearing compliance, therefore, is one of three fundamental constraints that limit the access-time performance of an actuator. To obtain improved access-time performance from a disk file, the following should be optimized: the air-bearing slider, the actuator crash stop, and the actuator mechanical time constant. This paper presents relevant design considerations.

A simple finite element model for reactive sputter-deposition systems *by F. Jones and J. S. Logan, p. 680.* The method of finite element analysis is used to calculate oxygen-concentration profiles and oxygen-absorption rates at the substrate and along the shields in an rf magnetron reactive sputtering system having a 12-inch-diameter magnetron. Results for several shield arrangements are calculated as a function of oxygen flow rate. The approach used assumes the following: (i) The target is being sputtered in the metallic state; (ii) the oxygen-concentration profile in the system can be calculated from the diffusion equation; (iii) the maximum amount of oxygen that can be absorbed at any point in the system is proportional to the metal deposition rate at that point; (iv) the target absorbs no oxygen as long as it is in the metallic state. The relative metal deposition rate along the substrate and shields is calculated, normalized to the measured deposition rate at the substrate, and used as a boundary condition for the diffusion equation. The calculated oxygen flow rate for the formation of stoichiometric substrate films agrees with experimental results to within 15%. The critical flow rate at which the target oxidizes, Q_c, is measured experimentally and when used in the model gives an oxygen partial pressure of about $0.31 \cdot 10^{-6}$ torr at the sputtering track.

Computation of current distribution in electrodeposition, a review *by J. O. Dukovic, p. 693.* This paper reviews the research literature that has appeared since 1980 on computer calculations of current distribution in the field of electrodeposition. Key contributions and general trends are identified, with particular emphasis given to applications in

the electronics industry. The survey reveals how numerical models have provided the technology of electrodeposition with general understanding, predictive power, and the capability of optimizing deposit uniformity. Anticipated developments for the nineties are discussed.

Finite element analysis of planar stress anisotropy and thermal behavior in thin films *by K. F. Young, p. 706.* To show the capability and diversity of finite element analysis, we calculate three-dimensional planar anisotropic stress distributions for various thin-film geometries and materials in response to thermal and electrical stimuli, for specific boundary conditions. The simulated residual film stresses are verified with acoustic microscopy measurements, substrate flexure measurements, and the use of thermal environment techniques. Simple shapes are analyzed as building blocks for more complex structures. Effects of nonlinear electrical resistance are also analyzed.

Thermoelastic behavior of X-ray lithography masks during irradiation *by I. A. Shareef, J. R. Maldonado, Y. Vladimirsky, and D. L. Katcoff, p. 718.* This paper presents computer calculations of thermoelastic effects in X-ray lithography masks caused by the absorption of X-rays during exposure. Several mask structures are considered, with different substrate and absorber materials, using finite element analysis. Part I of the paper deals with short-pulse X-ray irradiation (e.g., from gas plasma, laser-heated plasma, or exploding wire sources), and Part II describes irradiation during exposure with a synchrotron-storage-ring X-ray source. For the short-pulse irradiation, results indicate a maximum rise in temperature on the mask of about 30°C for a 2-ns exposure with a 10-mJ/cm^2 X-ray pulse. Mechanical static analysis shows that the maximum stress in the absorber films, which is due to maximum temperature differences in the mask layers, occurs at the end of the pulse. The magnitude of the induced thermoelastic stress is found comparable to the intrinsic stress level of the mask materials (typically 2–5 $\times$ 10^8 dyn/cm^2). The analysis indicates that when pulse amplitudes reach 10 mJ/cm^2, there will be a need for experimental study of X-ray mask distortion during exposure to short X-ray pulses. A one-dimensional model is developed for the case of storage-ring irradiation. The model predicts distortions of the printed image due to a thermal wave developed on the mask by scanning on the X-ray beam. Experimental results are presented showing that the effect is negligible under normal operating conditions but may become noticeable for operation in vacuum or without proper heat sinks.

Pythagorean hodographs *by R. T. Farouki and T. Sakkalis, p. 736.* The hodograph of a plane parametric curve $\mathbf{r}(t) = \{x(t), y(t)\}$ is the locus described by the first parametric derivative $\mathbf{r}'(t) = \{x'(t), y'(t)\}$ of that curve. A *polynomial* parametric curve is said to have a *Pythagorean* hodograph if there exists a polynomial $\sigma(t)$ such that $x'^2(t) + y'^2(t) \equiv \sigma^2(t)$, i.e., $(x'(t), y'(t), \sigma(t))$ form a "Pythagorean triple." Although Pythagorean-hodograph curves have fewer degrees of freedom than general polynomial curves of the same degree, they exhibit remarkable attractive properties for practical use. For example, their arc length is expressible as a *polynomial* function of the parameter, and their offsets are *rational* curves. We present a sufficient-and-necessary algebraic characterization of the Pythagorean-hodograph property, analyze its geometric implications in terms of Bernstein–Bézier forms, and survey the useful attributes it entails in various applications.

Finding compact coordinate representations for polygons and polyhedra *by V. J. Milenkovic and L. R. Nackman, p. 753.* Practical solid modeling systems are plagued by numerical problems that arise from using floating-point arithmetic. For example, polyhedral solids are often represented by a combination of geometric and combinatorial information. The geometric information may consist of explicit plane equations, with floating-point coefficients; the combinatorial information may consist of face, edge, and vertex adjacencies and orientations, with edges defined by face–face adjacencies and vertices by edge–edge adjacencies. Problems arise when numerical roundoff error in geometric operations causes the geometric information to become inconsistent with the combinatorial information. These problems can be avoided by using exact arithmetic instead of floating-point arithmetic. However, some operations, such as rotation, increase the number of bits required to represent the plane equation coefficients. Since the execution time of exact arithmetic operators increases with the number of bits in the operands, the increased number of bits in the plane equation coefficients can cause performance problems. One proposed solution to this performance problem is to *round* the plane equation coefficients without altering the combinatorial information. We show that such rounding is NP-complete.

Finding the distance between two circles in three-dimensional space *by C. A. Neff, p. 770.* In this paper we investigate, from an algebraic point of view, the problem of finding the distance between two circles located in *doubleR*^{3}. We show, by combining a theorem about solvable permutation groups and some explicit calculations with a computer algebra system, that, in general, the distance between two circles is an algebraic function of the parameters defining them, but that this function is *not* solvable in terms of radicals. Although this result implies that one cannot find a "closed-form" solution for the distance between an arbitrary pair of circles in *doubleR*^{3}, we discuss how such an algebraic quantity can still be manipulated symbolically by combining standard polynomial operations with an algorithm for isolating the real roots of a polynomial in a convenient data structure for real algebraic numbers. This data structure and its operations have been implemented.

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Preface *by T. F. Kuech, p. 794.*

Design of low-temperature thermal chemical vapor deposition processes *by D. B. Beach, p. 795.* The importance of an integrated approach involving synthetic chemistry, physical chemistry, and chemical engineering to the development of new thermal chemical vapor deposition (CVD) processes for the production of thin-film electronic materials is discussed. Particular emphasis is placed on choosing precursor molecules with facile thermal decomposition pathways that lead to pure films at low temperatures. Two examples from our laboratories, the deposition of copper from trialkylphosphine cyclopentadienyl copper complexes and the deposition of gallium nitride from diethylgallium azide, are used to illustrate the principles of precursor selection, the design factors for the construction of thermal CVD reactors, and the selection of processing conditions that optimize production of the desired material. In addition, new work on the thermal CVD of copper using an advanced reactor and examples of selective copper deposition and conformal copper deposition using the reactor are presented.

Low-temperature Si and Si:Ge epitaxy by ultrahigh-vacuum/chemical vapor deposition: Process fundamentals *by B. S. Meyerson, p. 806.* This paper is an overview of work at the IBM Thomas J. Watson Research Center on the chemical and physical considerations underlying the development of a low-temperature chemical vapor deposition process, designated ultra high-vacuum/chemical vapor deposition (UHV/CVD). The origins of the rigorous vacuum and chemical purity requirements of the process are discussed. Operating in the range of 500°C, the process has made it possible to explore the use, in silicon-based devices and atomic-length-scale structures, of a number of metastable materials in the Si:Ge:B system. Also discussed is associated experimental work on the fabrication of high-speed heterojunction bipolar transistors and high-mobility two-dimensional hole-gas structures.

Selective epitaxial growth of silicon and some potential applications *by B. J. Ginsberg, J. Burghartz, G. B. Bronner, and S. R. Mader, p. 816.* In the selective epitaxial growth (SEG) of silicon, growth occurs only on exposed silicon areas of a silicon substrate. Substrate regions on which silicon growth is not desired are masked by a dielectric film, typically silicon dioxide or silicon nitride. Use of the process permits the fabrication of novel silicon devices and integrated-circuit structures. In this paper, an overview is presented of our studies on the SEG process at the IBM Thomas J. Watson Research Center. Aspects covered are the kinetics of the process using a $SiCl_4$ and H_2 gaseous mixture, the associated suppression of deposition on silicon dioxide and silicon nitride, and some potential applications of the process to the fabrication of bipolar devices and dynamic random access memory (DRAM) cells.

Advances in metalorganic vapor-phase epitaxy *by M. A. Tischler, p. 828.* Metalorganic vapor-phase epitaxy (MOVPE) has become a well-established technique for the epitaxial growth of layers of III–V compound semiconductors since its introduction in 1968. Use has been made of the technique to produce such layers and associated devices to very demanding specifications. This paper describes MOVPE, followed by an overview of work at the IBM Thomas J. Watson Research Center on the technique, with emphasis on doping and selective epitaxy. Device applications are included to highlight the need to take into account the influence of materials and growth phenomena in order to produce optimum devices.

Diamondlike carbon films by rf plasma-assisted chemical vapor deposition from acetylene *by A. Grill, B. S. Meyerson, and V. V. Patel, p. 849.* This paper is an overview of studies performed at the IBM Thomas J. Watson Research Center on diamondlike carbon (hydrogenated amorphous carbon) films, including some recent results on their tribological properties. The films were prepared by rf plasma-assisted chemical vapor deposition (PACVD) from acetylene. Their structure and composition were characterized by a variety of methods such as X-ray and TEM diffractometry, XPS, high-resolution ^{13}C NMR spectroscopy, and $H(^{15}N\alpha, \gamma)C$ nuclear-reaction profiling. Their adhesion to various substrates, coefficients of static and dynamic friction, and wear resistance were also characterized. It was found that the films were essentially amorphous, reaching their bulk composition after 40 nm of growth above the initial growth interface. Their bulk composition included about 40% hydrogen. More diamondlike carbon bonding was obtained at the initial growth interface than in the bulk range. The ratio of sp^2 to sp^3 carbon atoms was found to be 1.6, with virtually all sp^3 carbon atoms bound to one or more hydrogen atoms. The diamondlike carbon films (DLC) displayed excellent adhesion to the surface of Si. Furthermore, the films could be bonded to films of otherwise nonbonding metals, provided the metals formed stable silicides. By using an interfacial Si film several atomic layers thick, adhesion to the metal films could be improved to the extent that attempts to detach the DLC films fractured the underlying metal films. The adhesive DLC films were found to have a very high resistance to sliding wear and chemical attack, and are therefore useful in various applications as very thin protective coatings.

On-chip wiring for VLSI: Status and directions *by M. B. Small and D. J. Pearson, p. 858.* The thirty-year history of silicon integrated circuits has resulted in dramatic increases in both the number of devices per chip and circuit speed. A consequence of scaling to submicron dimensions is that the major component of propagation delay will transfer from the devices to the interconnecting "wires." Additionally, increased integration, together with scaling, leads to a need for more numerous interconnections on a chip and higher current densities. Accommodation to these changes will necessitate the use of new materials arranged in three-dimensional wiring structures which have the ability to make the most effective use of the area of the chip. Generic processing routes to

achieve the desired structures are reviewed and examples are presented of two experimental structures with layers of planar wiring and vertical vias between planes. One of these integrates aluminum-alloy wiring with tungsten vias in a silicon dioxide dielectric; the other integrates copper wiring and vias in polyimide dielectric with the goal of minimizing delay due to on-chip wiring.

Surface and interfacial energies of $CoSi_2$ and Si films: Implications regarding formation of three-dimensional silicon-silicide structures *by K.-N. Tu, p. 868.* Formation of three-dimensional, multilevel structures consisting of epitaxial silicon and silicide films is currently of interest in the microelectronics technology. However, such structures have been difficult to produce because of surface wetting differences. To obtain associated surface energy information, an analysis was carried out of published data on the kinetics of crystallization of amorphous $CoSi_2$ and Si films. The analysis indicated that the amorphous-to-crystalline interfacial energy of amorphous $CoSi_2$ films is about one-fourth that of amorphous Si films, from which it was inferred that the surface energy of epitaxial $CoSi_2$ films is less than that of epitaxial Si films. The approach used in the analysis is general and should be extendable to other systems.

Surface chemistry of the WF_6-based chemical vapor deposition of tungsten *by M. L. Yu, K. Y. Ahn, and R. V. Joshi, p. 875.* This paper is an overview of work at the IBM Thomas J. Watson Research Center on chemical aspects of the WF_6-based chemical vapor deposition of tungsten. The focus is on two deposition processes. In the first process, tungsten deposition occurs through the chemical reduction of WF_6 by a silicon substrate. The thickness of the tungsten film thus grown is limited by the transport of silicon through the deposited film. In the second process, deposition occurs in a WF_6–silane mixture by the following reactions: reduction of adsorbed WF_6 by a surface layer of silicon to form tungsten, and the concurrent dehydrogenation of the adsorbed silane to replenish the silicon. This process permits the deposition of tungsten on any substrate, provided the initial reaction of the substrate with the WF_6–silane mixture can provide a tungsten or silicon "seed" layer to initiate the reaction cycle. Furthermore, the process is not limited by tungsten film thickness and hence permits the deposition of relatively thick films. Although surface selectivity is possible with regard to materials such as high-quality SiO_2, on which such a seed layer cannot be formed, the selectivity is adversely affected by the presence of particulates.

Magnetic thin films in recording technology *by V. S. Speriosu, D. A. Herman, Jr., I. L. Sanders, and T. Yogi, p. 884.* This paper is a review of recent progress in magnetic thin films for use in recording media and heads. Emphasis is on work that has been carried out at IBM. Topics covered include thin-film media for high-density recording, laminated soft-magnetic films for controlling domains and extending the frequency range of inductive heads, exchange-biasing of magnetoresistive sensors, and magnetic multilayer structures.

Magnetic multilayer structures *by R. F. C. Farrow, C. H. Lee, and S. S. P. Parkin, p. 903.* This is an overview of work at the IBM Almaden Research Center on magnetic multilayer structures comprising one, several, or many magnetic films sandwiched between nonmagnetic films. In recent years there has been increasing interest in such structures because of their novel and potentially useful properties. Recent examples of magnetic multilayer structures grown by molecular beam epitaxy (MBE) and sputtering are described. It is seen that MBE and sputtering are complementary techniques for the preparation of such structures, and that the ability to modify their magnetic properties by suitably designing their architecture is a key to their further development.

Lanthanide gallate perovskite-type substrates for epitaxial, high-T_c superconducting $Ba_2YCu_3O_{7-\delta}$ films *by E. A. Giess, R. L. Sandstrom, W. J. Gallagher, A. Gupta, S. L. Shinde, R. F. Cook, E. I. Cooper, E. J. M. O'Sullivan, J. M. Roldan, A. P. Segmüller, and J. Angilello, p. 916.* Previous studies had indicated promising use of lanthanide gallate perovskite-type substrates for the deposition of epitaxial, high-T_c superconducting $Ba_2YCu_3O_{7-\delta}$ (BYCO) films. They were also found to have moderate dielectric constants (~25 compared to ~277 for $SrTiO_3$). This study was undertaken to further explore the use of $LaGaO_3$, $NdGaO_3$, $SrTiO_3$, MgO, and Y-stabilized ZrO_2 substrates, prepared from single-crystal boules grown by several suppliers using the Czochralski method. Films were prepared by cylindrical magnetron sputtering and laser ablation. Substrate evaluations included measurement of dielectric constant and loss, thermal expansion, and mechanical hardness and toughness. In addition to their moderate dielectric constants, they were found to have satisfactory mechanical properties, except for the twinning tendency of $LaGaO_3$. Lattice mismatch strains were calculated for orthorhombic BYCO films on a number of substrates. $NdGaO_3$ was found to have the best lattice match with BYCO, and is now available twin-free.

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Preface *by E. J. Farrell, p. 3.*

FEMvis: An interactive visualization tool for mechanical analysis *by G. P. Bala, p. 4.* Increasing competitiveness in the development and manufacturing of mechanically based products requires ever-increasing design and development cycles, and has stimulated the introduction of many computer-based tools to assist with mechanical design and analysis. Currently, strong emphasis is placed upon the *effectiveness* of such tools, and on their enhancement through improved *usability*. A major contribution to improved usability is the level of *interactiveness* of a tool. FEM*vis* is a tool that provides capabilities for interactive visualization of mechanical engineering analysis, including rotation, translation, and magnification of images; views of shape deformations, their time-evolution, and their superposition; visualizations of scalar fields in two and three dimensions using colored isolevels; blending of shape deformation images and isolevel images; visualizations of three-dimensional phenomena by moving a slicing plane through the image, showing cross-sectional deformations and isolevels; and visualizations of multiple shape deformations and multiple scalar fields during a single usage session. FEM*vis* has been implemented in a portable language and a portable graphics package, and can run on a spectrum of hardware platforms from workstations to mainframes. It has been applied to the mechanical analysis of direct-access storage devices (DASD), including stress, strain, modal, and deformation analyses. The interactive nature of FEM*vis* facilitates iterative design refinement and rapid prototyping.

Volume visualization of 3D finite element method results *by K. Koyamada and T. Nishio, p. 12.* This paper describes a method for visualizing the output data set of a 3D finite element method result. A linear tetrahedral element is used as a primitive for the visualization processing, and a 3D finite element model is subdivided into a set of these primitives, which are generated at every solid element. With these primitives, isosurfaces are visualized semitransparently from scalar data at each node point. Two methods are developed for the visualization of isosurfaces with and without intermediate geometries. The methods are applied to output data sets from some simulation results of a semiconductor chip. These are visualized, and the effectiveness of the method is discussed.

Visual interpretation of multidimensional computations and transistor design *by E. J. Farrell, P. A. Appino, D. P. Foty, and T. D. Linton, Jr., p. 26.* As digital simulations and computations become more complex, larger volumes of output are generated; the engineer must select a concise method of displaying the output and extracting relevant information. In this paper we describe an experimental system called the Visual Interpretation System (VIS), which provides a wide range of tools for managing the visualization of simulation data. The effectiveness of VIS results from an interactive interface which controls a database manager and a visualization manager. The database consists of entities called *data sets* that carry a complete description of the geometry and time-dependent behavior of various properties of a simulated physical object. Visualization management involves both 2D and 3D imaging in multiple display windows and animation. Three-dimensional data imaging is based on optical modeling with back-to-front perspective projection. The optical model assigns color and attenuation to each point on the basis of its data value. With the appropriate choice of attenuation and color, the user can display multiple 3D regions, either as solids or transparently. This approach is not based on surfaces, nor does it require the data to have spatial continuity. The usefulness of VIS is demonstrated with data from a large-scale simulation of a transistor. We demonstrate how 3D visualization techniques provide insight into the physics of isolation-trench-bounded devices at both room and low temperatures, which facilitates the development of improved designs.

Data visualization using a general-purpose renderer *by A. Doi, M. Aono, N. Urano, and K. Sugimoto, p. 45.* This paper describes a general approach to data visualization, based on the Rendering Subroutine Package (RSP). (RSP) is a general-purpose polygon-based renderer, and is IBM's first rendering application programming interface (API) for users who wish to develop their own applications. We present an overview of the system, details of the image synthesis tools, and several examples of the application of RSP to architectural CAD, molecular graphics, and computer tomography.

Interactive analysis of the topology of 4D vector fields *by R. R. Dickinson, p. 59.* Interactive visualization methods are now evolving in response to a need to provide more immediate access to particular features of interest to analysts at particular points in the space and time of their data. This paper focuses on feature extraction methods relevant to the analysis of vector fields. In vector fields, "critical points" are those points at which the vector magnitude passes through zero. The word "topology" is used to describe the interconnection patterns between critical points. Topology is central to the understanding of vector fields. It provides very succinct and precise summary information, and can be used to subdivide large fields into well-defined subregions. In this paper, methods for interactively creating maps of vector-field topology are described. The advantages offered by interactive methods in comparison with automatic methods are also discussed.

Picture processing and three-dimensional visualization of data from scanning tunneling and atomic force microscopy *by E. P. Stoll, p. 67.* We present an overview of the current status of picture processing and three-dimensional visualization of data from scanning tunneling microscopy and related techniques. The topics we cover include the physical

basis of the resolution limit and noise sources in scanning microscopes, the design and restoration filters, and methods of visualizing surface contours and other surface properties by use of shadowing, contour lines, and superimposed colors. Postprocessed images of gold, graphite, biological molecules, the active zone of a laser diode, and silicon illustrate the outstanding quality of these methods.

Displaying morphological and lithological maps: A numerically intensive computing and visualization application *by F. Barberi, R. Bernstein, M. T. Pareschi, and R. Santacroce, p. 78.* Algorithms for evaluating digital terrain models (DEMs) and elevation moments such as slope, aspect, relief, and curvature are discussed. Significant new applications based on the elaboration and display of such data are presented. The results show that the processed data can be used for environmental protection and to identify topography-dependent natural-disaster hazards.

IDB: An image database system *by A. Turtur, F. Prampolini, M. Fantini, R. Guarda, and M. A. Imperato, p. 88.* Specialized software and hardware tools are needed to work on digital color images; the usability of an image system implies the availability of such resources inside a coherent environment and a friendly user interface. Furthermore, a large volume of data must be efficiently stored and retrieved. To cope with these problems, the prototype of an image database system, named IDB, has been developed to manage image data in an integrated way. The important features of the system are distributed functions, a multi-user environment, interactivity, and modularity.

Visualizing structure in high-dimensional multivariate data *by F. W. Young and P. Rheingans, p. 97.* We present and discuss several dynamic statistical graphics tools designed to help the data analyst visually discover and formulate hypotheses about the structure of multivariate data. All tools are based on the notion of the "data space," a representation of multivariate data as a high-dimensional (hD) space which has a dimension for each variable (column of the data) and a point for each case (row of the data). The data space is projected orthogonally onto the "visual space," a three-dimensional space which is seen and manipulated by the data analyst. The visual space has a point-like object for each case and can have a vector-like object for each variable. The three dimensions of the visual space are orthogonal linear combinations of the variables. We discuss the notion of a "guided tour" of multivariate data space, and present guided-tour tools, including 1) 6D-rotation, a tool for dynamically rotating, in six-dimensional (6D) space, from one 3D portion of the data space to another while displaying the dynamically changing projection in the visual space; 2) hD-residualization, a tool that determines, at the user's request, the largest invisible 3D space—i.e., the largest 3D space is orthogonal to the visual space. This space is used with the visual space so that 6D-rotation can occur between two new 3D portions of the data space; 3) projection-cueing, a group of three tools that use change in object brightness as a cue to show change in aspects of the projection of objects from the data space to the visual space during hD-rotation. In addition to these tools for touring high-dimensional multivariate space, we discuss tools for manipulating the 3D visual space, and a tool for examining the relationship between two data spaces. Finally, we present a guided-tour implementation in which the user manipulates joysticks and sliders to dynamically and smoothly control the graphics tools in real time. A video supplement demonstrates the implementation.

Visualization of molecular dynamics via ray-tracing and animation in a vectorized environment *by G. N. Williams, E. L. Nelson, D. M. Barnett, and K. Parmley, p. 108.* Scientific visualization methodologies are being utilized increasingly in attempts to understand physical phenomena via mathematical and simulation model results. Presented herein are the results of a visualization project which produced a vectorized, high-resolution, ray-traced animation of the dynamics of a protein molecule. The resulting animation was recorded on 35-mm file, with a resolution of 1024×1024 pixels with 24 color bits. Run-time statistics were also collected which relate image generation parameter ranges and interdependencies.

Animation of computer simulations of two-dimensional turbulence and three-dimensional flows *by M. Briscolini and P. Santangelo, p. 119.* One of the most challenging problems in fluid dynamics is understanding the properties of turbulent flows. The advent of large supercomputers permits the investigation of turbulence with great accuracy in two dimensions, but full three-dimensional problems are physically more complex and their study is currently limited to the case of simple flows. It is shown that the availability of a continuous time-dependent representation of the dynamics of fluid flows can quickly lead to more complete understanding of the many concurrent physical mechanisms ruling turbulence. Some significant examples show how an analog videotape, obtained from direct computer simulations of fluid flows, suggests physical results that can later be obtained through a mathematical analysis of the numerical simulations.

A numerically intensive computing environment: IBM 3090 and the PS/2 Model 80 *by R. F. Arnold, P. Halpern, G. R. Hogsett, B. T. Straka, C. Arasmith, and J. McElroy, p. 140.* Recent advances in personal computer workstations, such as the IBM Personal System/2® Model 80 with its increased memory and CPU speed, loosely coupled with a host IBM 3090™ Processor, can provide considerable computing advantages for executing and visualizing numerically intensive computing (NIC) applications. We have developed a prototype visualization environment which demonstrates effective use of this hardware. The user interface for the NIC application is written using Microsoft Windows® on the PS/2® Model 80 running DOS 3.3. The PS/2 Model 80 is connected to a host 3090 via a PC network. The user enters requests which are application parameters and

selects graphic views for displaying the output results file. The entries are made through user dialog screens on the workstations. The user view of the system is such that it appears that it is running on the workstation. To achieve this transparency, caches are used on both the workstation and the host. The cache on the host is in the form of graphic metafiles and numeric data. The cache on the workstation contains metafiles. Requests are monitored on the workstation to determine whether the results are in the local cache. When they are not, a request file is transferred to the host and checked against the host cache. The NIC application is run only when the requested result is not in either cache. In order to reduce the file size, the results file is converted to a metafile before being transferred to the workstation.

Application of visualization tools in solid mechanics *by S. Moini, p. 156.* With increasingly complex digital simulations and computations, large volumes of numerical output are generated, and users must select more effective techniques for handling and displaying such output in order to extract relevant information. In this study, visualization techniques such as animation, tracking, and 2D/3D color displays are imbedded in implicit and explicit finite element codes for solving complex solid-mechanics problems. With these techniques, the investigator can more fully utilize computer time and better understand the results of long and costly computations. This investigation demonstrates the effectiveness of different visualization techniques and distributed computing on an IBM platform.

Graphic workstations and supercomputers: An integrated environment for simulation of fluid dynamics problems *by F. Piccolo, V. Zecca, A. Grimaudo, and C. Loiodice, p. 167.* An integrated environment for simulation and visualization of physics and engineering problems of industrial interest has been set up at the IBM European Center for Scientific and Engineering Computing (ECSEC). This paper describes the environment, its components, and some experiments carried on at ECSEC to represent 3D objects displayed with the shading technique and the solution of fluid dynamics problems, all treated with the finite element method. Moreover, the paper describes the animation experiments developed to represent dynamics phenomena (fluid flows) and presents a videotape showing the time evolution of three fluid dynamics study cases.

Correlative visualizaton techniques for multidimensional data *by L. A. Treinish and C. Goettsche, p. 184.* Critical to the understanding of data is the ability to provide pictorial or visual representations of those data, particularly in support of correlative data analysis. Despite the many advances in visualization techniques for scientific data over the last several years, there are still significant problems in bringing today's hardware and software technology into the hands of the typical scientist. For example, there are computer science domains other than computer graphics, such as data management, that are required to make visualization effective. Well-defined, flexible mechanisms for data access and management must be combined with rendering algorithms, data transformations, etc. to form a generic visualization pipeline. A generalized approach to data visualization is critical for the correlative analysis of distinct, complex, multidimensional data sets in the space and earth sciences. Different classes of data representation techniques must be used within such a framework, which can range from simple, static two- and three-dimensional line plots to animation, surface rendering, and volumetric imaging. Static examples of actual data analyses will illustrate the importance of an effective pipeline in a data visualization system.

Interactive Quantitative Visualization *by R. L. Peskin, S. S. Walther, A. M. Froncioni, and T. I. Boubez, p. 205.* Interactive Quantitative Visualization, a methodology to enhance scientific and engineering computational simulation prototyping, is defined. Appropriate strategies for implementing IQV in a workstation-based distributed computing environment are discussed. Object-oriented graphical tools and a new data management technique to support IQV and computational steering are described. Two examples of IQV and computational steering are presented: 1) a system to allow interactive solution and visualization of nonlinear boundary-value problems; and 2) a modeling exercise illustrating how IQV and computational steering are used together to prototype simulation of a complex physical system, namely a flag flapping in the wind.

Picturing randomness on a graphics supercomputer *by C. A. Pickover, p. 227.* This paper provides a light introduction to a simple graphics technique which can be used to represent random data on a graphics supercomputer. The representation, called a "noise-sphere," can be used to detect "bad" random-number generators with little training on the part of the observer. The system uses lighting and shading facilities of 3D extensions to the X-Windows or the PHIGS+ standard. To encourage reader involvement, computational recipes and suggestions for future experiments are included.

An interactive graphic tool to plot the structure of large sparse matrices *by G. V. Paolini and P. Santangelo, p. 231.* Many engineering and scientific problems involve the solution of large sparse linear systems. To determine an optimal solving strategy for such systems, it is essential to understand the large- and small-scale properties of the associated sparse matrices. We present a graphic tool to analyze the sparsity pattern and the numeric structure of these matrices. Through examples, drawn from our practical experience, we demonstrate the effectiveness and the interactive features of the tool. These features include zooming, scrolling in different directions, sorting of rows and/or columns, and selective plotting, according to the values of the matrix coefficients.

Visualization in a VLSI design automation system *by D. L. DeMaris, p. 238.* Problems unique to the visualization of

successfully. The implications of these results for hierarchical networks, a class of networks for interconnecting a highly parallel, shared-memory multiprocessor computer system, are discussed.

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Preface *by W. Nohilly, S. Hajek, and R. Hawryluk, p. 306.*

The IBM Enterprise System/9000 Type 9121 air-cooled processor *by S. F. Hajek, p. 307.* The IBM Enterprise System/9000™ Type 9121 air-cooled processor achieves, with the same or reduced physical floor space and power levels, a performance level equal to or greater than those of previous IBM processors. This performance level was attained by a combination of design innovations: a new air-cooled thermal conduction module (TCM), integration of bipolar and CMOS technology in this TCM, the design and implementation of a differential current switch bipolar circuit family, integrated programmable memory subsystem design, and extensive use of VLSI technology. The result of these innovations was a 15-ns-cycle air-cooled machine. The salient features and an overview of the machine design are presented.

Differential current switch—High performance at low power *by E. B. Eichelberger and S. E. Bello, p. 313.* The recent IBM System/390® announcement includes six high-performance air-cooled models that use a low-power variation of emitter-coupled logic (ECL). This new logic family, called differential current switch (DCS), uses differential signal pairs to represent logic signals, and combines two-level cascode logic with dotting to implement a complete set of logic circuits. These DCS circuits are described in detail, and the relative value of the DCS and ECL logic families is discussed extensively.

A 128Kb CMOS static random-access memory *by J. L. Chu, H. R. Torabi, and F. J. Towler, p. 321.* This paper describes an all-CMOS 128Kb static random-access memory (SRAM) with emitter-coupled-logic (ECL) I/O compatibility which was designed for the air-cooled Enterprise System/9000™ processors. Access time of 6.5 ns is achieved using 0.5-μm channel length and 1.0-μm minimum geometry. Pipelining and self-resetting circuit techniques permit the chip to operate with cycle time less than access time. To achieve the high-reliability requirement in the TCM environment, a novel technique utilizing a sacrificial substrate is used to "burn in" chips prior to their attachment to the TCM.

IBM System/390 air-cooled alumina thermal conduction module *by J. U. Knickerbocker, G. B. Leung, W. R. Miller, S. P. Young, S. A. Sands, and R. F. Indyk, p. 330.* Advances in multilayer ceramic (MLC) processing, the use of thin-film metallurgy wiring, and enhancements in thermal dissipation, all described in this paper, represent significant milestones in the evolution of microelectronic packaging technology. The IBM System/390® air-cooled alumina thermal conduction module (S/390® alumina TCM) utilizes a 127.5 × 127.5-mm MLC substrate to interconnect as many as 121 VLSI devices and 144 substrate-mounted decoupling capacitors. The substrate provides an array of 648 pads for solder connections to each device, an array of 16 pads for solder connections to each capacitor, and an array of 2772 pins for interconnection with the next package level, and contains approximately 400 m of wiring. The reduced thermal resistance design permits up to 600 W of air-cooling capacity. This paper describes the S/390 alumina TCM fabrication processes and discusses the advances they represent in processing technology, packaging density, and performance. Comparisons to prior technology are made.

IBM Enterprise System/9000 Type 9121 Model 320 air-cooled processor technology *by V. L. Gani, M. C. Graf, R. F. Rizzolo, and W. F. Washburn, p. 342.* The basic component of the new IBM Enterprise System/9000™ Type 9121 Model 320 processor is an air-cooled thermal conduction module (TCM). The fabrication of this module required the integration of new bipolar chips, CMOS SRAM chips, and ECL and DCS logic circuitry in a TCM that could dissipate heat by means of air cooling. The method and details of this process of integration are described and discussed.

An adder design optimized for DCS logic *by A. Weinberger, p. 352.* The basic DCS logic gate provides a two-way SELECT function and, with modifications, a two-way XOR, OR, or AND function. Furthermore, outputs of DCS gates can be wired together (dotted) to perform dotted SELECT, XOR, OR, or AND functions. The versatility of this logic is illustrated in the design of a carry-lookahead adder.

IBM Enterprise System/9000 Type 9121 system controller and memory subsystem design *by B. W. Curran and M. H. Walz, p. 357.* A system controller supporting two processors, two independent memory banks, and a channel subsystem has been implemented within a single air-cooled thermal conduction module for the IBM Enterprise System/9000™ Type 9121 processors. Improvements in technology densities, usage of CMOS and emitter-coupled logic on the same substrate, and innovations in the system controller design were required to achieve the one-module objective. In addition, system reliability is improved with a storage key error-correction code, and storage allocation options are increased with a combined main/expanded store design. In conjunction with the system controller development, a new memory subsystem has been designed for the 9121 system. Innovative large-system memory packaging techniques and functional changes in the data accessing methods have culminated in a memory board which supports up to one-gigabyte system storage.

Design and performance of the IBM Enterprise System/9000 Type 9121 Vector Facility *by T. J. Slegel and R. J. Veracca, p. 367.* The design of the IBM Enterprise System/9000™ Type 9121 Vector Facility is described and its

complex, partially automated design tasks such as VLSI system design are reviewed, and approaches are described. The design domain used to illustrate the approaches is chip-level "floor-planning," an iterative-refinement design methodology for VLSI layout, routing and timing control. The general view structure and control structure are described. Other visualization topics addressed are display of evolving data, sequencing of overlay data, an interleaved temperature–color metaphor for view consistency and clarity, and dynamically generated iconic measurement tools.

Visualizing processes in neural networks *by J. Wejchert and G. Tesauro, p. 244.* A real-time visualization toolkit has been designed to study processes in neural network learning. To date, relatively little attention has been given to visualizing these complex, nonlinear systems. Two new visualization methods are introduced and then applied. One represents synaptic weight data as "bonds" of varying length embedded in the geometrical structure of a network. The other maps the temporal trajectory of the system in a multidimensional configuration space as a two-dimensional diagram. Two-dimensional graphics were found to be sufficient for representing dynamic neural processes. As an application, the visualization tools are linked to simulations of networks learning various Boolean functions. A multiwindow environment allows different aspects of the simulation to be viewed simultaneously using real-time animations. The visualization toolkit can be used in a number of ways: to see how solutions to a particular problem are obtained; to observe how different parameters affect learning dynamics; and to identify the decision stages of learning. A demonstration videotape is provided.

Three-dimensional visualization of many-body system dynamics *by M. Bernaschi, E. Marinari, S. Patarnello, and S. Succi, p. 254.* This paper describes a graphic rendering system for use in visualizing the behavior of three-dimensional physical systems. The tool is general and allows the user to characterize a great variety of phenomena. The only requirement is that the physical system be represented by variables defined on quantifiable positions (sites) within a three-dimensional grid. The variables may be discrete (e.g., binary), real, or even complex numbers. The first part of the paper gives a technical description of the graphic program, which is based on a graPHIGS™ interface; two versions of the code (in the C and FORTRAN languages) are available. The hardware platform consists of an IBM 5080 graphic workstation with a 5081 high-resolution monitor which can be driven either by a machine employing IBM System/370™ architecture with VM/XA™ (in our case a 3090™ processor running under VM/XA) or by a RISC System/6000® workstation [we have used both an IBM RT® System and (recently) an IBM RISC System/6000 processor] running under AIX®. The second part of the paper describes three different examples of the application of this tool: discrete spin models, quantum chromodynamics (QCD), and three-dimensional turbulence. For spin systems and QCD, the physical problem consists in understanding the nature of the phase transition from disordered to ordered states of the system. In both cases a direct (i.e., through visualization) investigation of the system configurations reveals valuable information about properties such as the order of the transition, the behavior of the correlation length, and phase coexistence. We note, however, that the meaning of the site variables is very different in the two cases. In particular, for QCD the site variables are complex numbers, which we code by using a color table to represent the phase of the number and pixel size to represent a value proportional to the modulus. This kind of coding is also used for three-dimensional turbulence. Here the analysis can show where dissipation phenomena take place in the fluid and characterize the geometrical nature of the set of dissipative structures.

Visualizing parallel execution of FORTRAN programs *by F. Szelényi and V. Zecca, p. 270.* As a first step toward the parallel execution analysis of FORTRAN programs, a tool called the Parallel Execution Profiler has been designed and implemented for the graphical postexecution analysis of parallel programs using the Parallel FORTRAN environment as a vehicle for both implementing parallel programs and tracing parallel events. The dynamic behavior of parallel execution is observed interactively in color graphs, which can be displayed concurrently with the source code, and in statistical summaries. This paper describes the implementation of our tool for parallel performance analysis with the aid of a parallelized application program from plasma physics.

A 3072 × 32-stage TDI imaging device *by E. S. Schlig, p. 283.* A 3072 × 32-stage TDI charge-coupled imaging device is described. It is believed to be the first reported TDI imager suitable for 300-pel-per-inch document scanning. Its large photocharge capacity gives it the noise performance and dynamic range required for high-quality gray-scale and color imaging in publishing and museum applications. Design options for high-resolution TDI imagers and the uniformity enhancement provided by the TDI mode of operation are discussed.

Traffic studies of unbuffered Delta networks *by P. Heidelberger and P. A. Franaszek, p. 288.* This paper analyzes the performance of unbuffered Delta networks under a nonuniform ("hot-spot") traffic pattern. Particular attention is paid to characterizing the overflow traffic of unsuccessfully transmitted packets. Analytic techniques are used to show that the overflow traffic from an unbuffered packet-switched Delta network is (fractionally) hotter than the offered load. Simulation techniques are used to extend this result to an unbuffered circuit-switched network with limited retrials. In addition, the distribution of the number of trials until a "cold" packet is successfully delivered is shown to have a decreasing hazard rate, which means that it becomes less and less likely with each successive trial that a packet is delivered

performance is evaluated in this paper. The Vector Facility design adheres to the architecture developed for the 3090™ vector facilities. The original design objectives and associated architecture are reviewed. Vector operations and design details are discussed, and specific performance results are shown.

Two approaches to array fault tolerance in the IBM Enterprise System/9000 Type 9121 processor *by P. R. Turgeon, A. R. Steel, and M. R. Charlebois, p. 382.* The system design of the IBM Enterprise System/9000™ Type 9121 processor was intended to provide high performance and dense packaging within an air-cooled system. Packaging and technology factors had a major influence on the fault-tolerance strategies chosen. This paper describes the effect that this design point had on the fault-tolerant capabilities of two critical 9121 array applications. Although the design challenges faced by these array applications initially appeared to be very similar, the resulting solutions represent very different designs with differing fault-tolerance capabilities. The rationale for these approaches is given, and the error-correction algorithms are described.

Enhanced self-test techniques for VLSI systems applied to the IBM Enterprise System/9000 Type 9121 processor *by S. Sarma, p. 390.* This paper discusses the problems associated with obtaining adequate test coverage from random self-test for thermal conduction modules (TCMs) in the air-cooled IBM Enterprise System/9000™ Type 9121 processors. Each 9121 TCM contains approximately a quarter of a million circuits. The present complexity of the TCMs made previous testing methods such as chip-in-place (CIP) testing inviable. The solution was to apply self-test techniques to the 9121 TCMs during the manufacturing process. Analytical and simulation techniques were used to predict the random-pattern testability of the TCMs. The results of the self-test process for the five distinct 9121 processor TCMs are presented. Methods of identifying and modifying random-pattern-resistant logic structures are discussed. It is also proposed that a hybrid approach combining random self-test with deterministic test generation can be used to enhance testability.

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Making negatives and plates for printing by electroerosion: Introduction and overview *by K. S. Pennington, p. 458.* The most familiar electroerosion printers operate by removing the whitish or silvery aluminum overlayer from discrete areas of a special paper so as to reveal a black underlayer. The direct negative/direct plate (DNP) material described here is a new dual-function printing material which, when employed together with an electroerosion printer, allows direct generation of negatives or (short-run) offset printing plates suitable for use in printing and publishing applications. The DNP material has been specifically developed for use with the IBM 4250 electroerosion printer family, allowing these printers to generate negatives, plates, and camera-ready copy directly from the computer with no chemical processing.

Making negatives and plates for printing by electroerosion: I. Physical principles *by M. S. Cohen and K. S. Pennington, p. 466.* Electroerosion printing involves removal of the aluminum overlayer from selected areas of a black-coated paper. "Direct negatives" as well as "direct plates" for use in offset lithographic printing may also be generated by electroerosion if a clear polymer sheet is used as the substrate instead of paper, and the black base layer is omitted. If such a substrate is metallized and written by electroerosion, the desired direct negative is created in principle since the metal stops transmitted light and the polyester does not. The direct plate is simultaneously created in principle since the aluminum is hydrophilic and the polyester is hydrophobic. Practical realization of these concepts required studies of the physical principles of the processes involved, which led to techniques for avoidance of mechanical scratching of the aluminum film during writing. For this purpose a mechanically hard underlayer was applied to the substrate under the aluminum, while a very thin lubricating overlayer having some electrical conductivity was applied over the aluminum. The underlayer consisted of silica particles in an organic binder, while the overlayer consisted of graphite particles in a binder. Although scratching is less for smooth than for rough underlayers, rough underlayers were preferred because they offered better writing reproducibility. In particular, debris created during writing was scoured away from the styli in rough-underlayer samples. For writing, a two-phase driver was used, in which the first phase provided a high current for Joule heating with consequent breaking of direct local aluminum–stylus contacts, while the second phase provided an arc which removed the remainder of the aluminum under the stylus.

Making negatives and plates for printing by electroerosion: II. Larger-scale fabrication and testing *by M. S. Cohen, A. Afzali, E. E. Simonyi, M. Desai, and K. S. Pennington, p. 489.* The principles of producing direct negatives and direct plates by electroerosion writing were given in Part I of the present series of papers. Part II is concerned with larger-scale fabrication techniques, characterization methods, and the results of tests, together with their interpretation. Major problems which were encountered are also presented with their solutions. sheet material for the direct negative/direct plate (DNP) was made by 1) Coating polyester rolls with an underlayer. The underlayer coating fluid contained silica, a cellulosic binder, a saturated polyester dispersant, and an isocyanate cross-linker. The coating fluid was carefully milled to control silica particle size before coating. 2) Curing the rolls either at ambient or elevated temperature. 3) Calendering the underlayer. 4) Vacuum-depositing an aluminum film. 5) Coating with an overlayer containing graphite and a binder. Maintenance of good control of material characteristics was

found essential for acceptable functional performance. Among the parameters requiring control were underlayer thickness and surface roughness, aluminum thickness, and overlayer thickness, as well as the composition of the various components. After fabrication, functional testing of the DNP material was carried out on the IBM 4250 printer in order to study the major performance problems of scratching, writing failure, head wear, gouging, and head fouling. Scratching could be suppressed by decreasing the surface roughness and increasing the thickness of the overlayer. Writing efficiency could be improved by increasing the roughness, decreasing the overlayer thickness, decreasing the aluminum thickness, and increasing the pulse length. Head wear could be suppressed by calendering and reducing the roughness. Gouging and excessive head wear could be suppressed by adequate milling, dispersing and filtering of the underlayer coating fluid, and calendering and curing of the coated web, while ensuring good underlayer–substrate adhesion. Fouling was reduced by decreasing the overlayer thickness and reducing the writing pulse length.

Making negatives and plates for printing by electroerosion: III. Use of the direct negative and direct plate *by M. S. Cohen, A. Afzali, E. E. Simonyi, and K. S. Pennington, p. 512.* Issues related to the practical usage in the pressroom of both the direct negative and direct plate are discussed. Two concerns associated with the usage of the *direct negative* during platemaking are treated: 1) the effect of light transmission through defects (voids) in the aluminum film, and 2) the effect of light transmission directly through the aluminum. These concerns may be addressed respectively by careful fabrication of the material and careful control of the exposure conditions during platemaking. Two aspects of the usage of the *direct plate* are considered: 1) the need for a simple prepress "activation" treatment, and 2) press-life limitations caused by wear of the direct plate on the press. Passing a direct plate through an activator solution immediately prior to mounting it on the press prevented scumming in the image area and blinding in the background (nonimage) area. The life on the press of the direct plate is limited by the wearing away of the aluminum from the background areas, thereby causing scumming. Changes in the structure of the direct plate which could prolong press life were investigated.

The art of fractal landscapes *by F. K. Musgrave and B. B. Mandelbrot, p. 535.* Synthetic images of fractal landscapes have moved beyond science to enter the domain of "art for art's sake." We discuss some of the ramifications of this artistic aspect: improving the fractal description of terrains, adding fractal textures to surfaces, and using parallel computers. We illuminate the peculiarities of attaining artistic self-expression in representational imagery purely through formal logic, and discuss its import.

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Preface *by W. Kleinfelder, p. 571.*

The IBM Victor V256 partitionable multiprocessor *by D. G. Shea, W. W. Wilcke, R. C. Booth, D. H. Brown, Z. D. Christidis, M. E. Giampapa, G. B. Irwin, T. T. Murakami, V. K. Naik, F. T. Tong, P. R. Varker, and D. J. Zukowski, p. 573.* Victor V256 is a partitionable message-passing multiprocessor with 256 processors, designed and in use at the IBM Thomas J. Watson Research Center. Our goals are to explore computer architectures based on the message-passing model and to use these architectures to solve *real* applications. We present the architecture of the Victor system, particularly its partitioning and nonintrusive monitoring. We discuss some of the programming environments on Victor, such as E-kernel, an embedding kernel developed for the support of program mapping and network reconfiguration. We review applications developed and run on Victor and discuss a few in depth, concluding with insights we have gained from this project.

Design choices for the TOP-1 multiprocessor workstation *by S. Shimizu, N. Oba, T. Nakada, M. Ohara, and A. Moriwaki, p. 591.* A snoopy-cache-based multiprocessor workstation called TOP-1 (TOkyo research Parallel processor-1) was developed to evaluate multiprocessor architecture design choices as well as to conduct research on operating systems, compilers, and applications for multiprocessor workstations. TOP-1 is a ten-way multiprocessor using the Intel 80386™ microprocessor chip and the Weitek WTL 1167™ floating-point coprocessor chip. It is currently running under a multiprocessor version of AIX®, which was also developed at the IBM Tokyo Research Laboratory. Our research interest was focused on the design of an effective snoopy cache (all caches monitor all memory-cache traffic) system and the quantitative evaluation of its performance. One of the unique aspects of the TOP-1 design is that the cache supports four different, original snoopy protocols, which may coexist in the system. To evaluate the performance, we implemented a hardware statistics monitor that gathers statistical data. This paper focuses mainly on the TOP-1 cache design—its protocol, and its evaluation by means of the statistics monitor. Besides its cache design, TOP-1 has three other unique architectural features: two independently arbitrated 64-bit buses supported by two snoopy-cache controllers per processor, a communication and interruption mechanism for notifying other processors of asynchronous events, and an efficient arbitration mechanism to allow prioritized quasi-round-robin service with distributed control. These features are also described in detail.

Hierarchically interconnected multiprocessors *by P. A. Franaszek, C. J. Georgiou, and A. N. Tantawi, p. 603.* The

design of interconnection networks is a central problem in parallel computing, especially for shared-memory systems, where network latency, or delay, is one factor that limits system size. This paper discusses aspects of one particular approach to network structure, a design comprising a multiplicity of subnetworks that form a hierarchy of paths. The hierarchy includes fast paths that are used in the absence of contention, and alternate paths with contention resolution. That is, just as in the case of a memory hierarchy, the fastest component of the hierarchy that can provide the desired function is utilized at a given time. The viability and robustness of hierarchical networks is studied first by examining circuit and implementation issues, and then by considering performance modeling and analysis. The overall performance of the hierarchy is shown to be close to that of a contention-free network of fast paths.

Operating system support for parallel programming on RP3 *by R. M. Bryant, H.-Y. Chang, and B. S. Rosenburg, p. 617.* RP3, the Research Parallel Processing Prototype, was a research vehicle for exploring the hardware and software aspects of highly parallel computation. RP3 was a shared-memory machine that was designed to be scalable to 512 processors; a 64-processor machine was in operation from October 1988 through March 1991. A parallel-programming environment based on the Mach operating system was developed, and a variety of programming models were tested on the machine. To help user programs realize the full potential of parallelism on RP3, the RP3 operating system was extended to support such RP3 architectural features as noncoherent caches, local and interleaved storage, and a hardware performance monitor. The system included explicit job-scheduling and processor-allocation facilities, facilities for exploiting the RP3 memory hierarchy, and performance-data collection and logging facilities. This paper describes these components of the RP3 operating system, provides the rationale for the design decisions that were made, and discusses the implementation of these operating system facilities.

The RP3 program visualization environment *by D. N. Kimelman and T. A. Ngo, p. 635.* The performance promised for parallel systems often proves to be somewhat elusive. This paper discusses one important technique for improving the performance of parallel software: *program visualization*—helping programmers visualize the real behavior of an application or system by presenting its state and progress in a continuous graphic fashion. An environment for visualization of program execution is described. Within this *visualization environment*, programmers dynamically establish views of the behavior of a program in execution and watch for trends, anomalies, and correlations as information is displayed. By continually refining the view of the program and replaying the execution of the program, programmers can gain an understanding of program (mis)behavior. This is essential for the debugging, performance analysis, and tuning of parallel software. Design goals for the visualization environment include expandibility, portability, and the ability to accommodate diverse architectures, including highly parallel shared-memory systems and large-scale message-passing systems. Results from visualization of systems and applications running on the RP3, an experimental shared-memory multiprocessor, are presented in the form of color reproductions of typical, useful displays.

The Parallel Processing Compute Server *by E. M. Ammann, R. R. Berbec, G. Bozman, M. Faix, G. A. Goldrian, J. A. Pershing, Jr., J. Ruvolo-Chong, and F. Scholz, p. 653.* The Parallel Processing Compute Server (PPCS) is a distributed-memory multiprocessing system consisting of System/370™ microprocessors (33 at present) interconnected through a matrix switch. This paper describes the hardware configuration, the extensions to the System/370 instruction set that are provided to support the distributed memory and interprocessor signaling, the modifications to the VM/SP operating system that allow it to run effectively on many closely coupled processors (most of which have no disks), and the application-support layer, which permits FORTRAN programs to take advantage of the highly parallel environment. Development of the PPCS is a joint effort of the IBM Böblingen Development Laboratory and the IBM Thomas J. Watson Research Center. A prototype PPCS has been installed at CERN.

Clustering IBM Enterprise System/3090 computers for parallel execution of FORTRAN programs *by L. J. Scarborough, R. G. Scarborough, and S. W. White, p. 667.* Two IBM Enterprise System/3090™ Model 600J computer systems, each with six processors capable of executing vector and scalar instructions, have been connected into a cluster for parallel execution of single FORTRAN programs. The clustering is achieved through a combination of software and hardware. When enabled for parallel execution and allowed to use all twelve processors in the cluster, FORTRAN programs have run as much as 11.7 times faster than when run on a single processor. The combined hardware and software technology is called IBM Clustered FORTRAN. It was achieved by modifying existing technology quickly to provide new capabilities. This paper discusses the modifications and the motivations behind them. It summarizes the performance of several applications executed with Clustered FORTRAN. Finally, it describes how clustering has been used to improve performance in novel ways.

Exploiting database parallelism in a message-passing multiprocessor *by R. A. Lorie, J.-J. Daudenarde, J. W. Stamos, and H. C. Young, p. 681.* Parallel processing may well be the only means of satisfying the long-term performance requirements for database systems: an increase in throughput for transactions and a drastic decrease in response time for complex queries. In this paper, we review various alternatives, and then focus entirely on exploiting parallel-processing configurations in which general-purpose processors communicate only via message passing. In our

configuration, the database is partitioned among the processors. This approach looks promising but offers challenging problems. The paper reports on our solutions to some of them: how to express strategies for efficiently executing complex queries, how to minimize overhead in operations such as parallel joins and sorts, and how to deal with transaction management in a highly distributed system. The paper ends with a discussion of the lessons we learned from exercising a prototype developed in IBM Research.

Multiplication of a symmetric banded matrix by a vector on a vector multiprocessor computer *by R. Reuter, U. Scharffenberger, and J. Schüle, p. 697.* This paper describes how to vectorize and parallelize the multiplication of a symmetric banded matrix by a vector, on a vector multiprocessor. The ideas presented involve two packed-band-storage schemes, and implementations for both schemes are studied. The best among the uniprocessor solutions proposed achieves a maximum of 37.1 Mflops on an IBM Enterprise System/3090™ 400E with Vector Facility (VF). For one of the schemes, a parallel implementation on an IBM 3090™ VF multiprocessor is presented, and time measurements are discussed.

Waveform-relaxation-based circuit simulation on the Victor V256 parallel processor *by T. A. Johnson and D. J. Zukowski, p. 707.* Present-day circuit-analysis tools permit designers to verify performance for circuits consisting of up to 10,000 transistors. However, current designs often exceed several tens of thousands and even hundreds of thousands of transistors. The gap between the number of transistors that can be simulated and the number per design inhibits proper analysis prior to manufacturing, yet incomplete analysis often overlooks design flaws and forces redesign, resulting in increased costs and longer development times. This gap is expected to widen in the foreseeable future. To help close the ever-increasing simulation/design gap, we have developed an experimental parallel circuit simulator, WR_V256, for the Victor V256 distributed-memory parallel processor. WR_V256 has been used to analyze circuits from fewer than 300 to more than 180,000 MOSFETs. WR_V256 was originally based on a Gauss–Seidel relaxation algorithm, which was later replaced with a bounded-chaotic one in order to achieve good parallel speedups for a wider variety of circuits. At this time, speedups of up to 190 have been observed for large circuits.

Further results using the overhead model for parallel systems *by H. P. Flatt, p. 721.* A performance model that takes into consideration the overhead incurred in the use of a parallel system is used to show that the maximum value of the speedup achieved by the parallel system for a fixed problem may be much smaller than the number of processors required to achieve that value. It is also shown that under certain conditions, the problem size may be varied so as to achieve a speedup closely approximating the number of processors used.

The parallel C (pC) programming language *by R. Canetti, L. P. Fertig, S. A. Kravitz, D. Malki, R. Y. Pinter, S. Porat, and A. Teperman, p. 727.* We describe pC (parallel C), an extension of the ANSI C programming language to support medium- to large-grain parallel programming in both shared- and distributed-memory environments. pC aims to make programming for parallel processors accessible to the C community by enriching the C programming model with a small set of constructs supporting parallelism. pC supports shared- and distributed-memory environments via a hierarchical computational model. A pC application comprises a static collection of *tasks* with disjoint memory spaces. A dynamic collection of *threads* runs within each task, sharing the data and code of the task. Language constructs specify concurrent execution of threads within a single task. Additional language constructs specify the interactions between threads through the following mechanisms: initiation of threads in remote tasks by *remote function call*, mailbox-based message passing, and synchronization primitives. The paper introduces the computational model and language constructs of pC and describes a prototype pC compiler and run-time system for the Mach operating system. Several program examples illustrate the utility of pC constructs.

Low-overhead scheduling of nested parallelism *by S. F. Hummel and E. Schonberg, p. 743.* Nested parallelism has the potential not only to permit more parallelism than non-nested parallelism, but to result in better load balancing. However, nested parallelism will not be profitable unless the overhead of scheduling nested parallel constructs can be made nonprohibitive. Previous implementations of nested parallel constructs have been fairly expensive and therefore have not been able to exploit fine-grained nested parallelism. In this paper, we describe a run-time system that schedules a large subset of nested parallel constructs—those that run until completion without blocking—with very little overhead. Our run-time system is built around a novel scheduling policy and work queue. The scheduling policy permits efficient stack-based local-memory storage allocation for task data, which is particularly efficient for multiprocessor architectures with both shared and local memory, such as the RP3. The shared, nonlocking work queue allows processors to obtain tasks in just a few instructions, without sacrificing load balancing.

Execution of automatically parallelized APL programs on RP3 *by W.-M. Ching and D. Ju, p. 767.* We have implemented an experimental APL/C compiler, which accepts ordinary APL programs and produces C programs. We have also implemented a run-time environment that supports the parallel execution of these C programs on the RP3 computer, a shared-memory, 64-way MIMD machine built at the IBM Thomas J. Watson Research Center. The APL/C compiler uses the front end of the APL/370 compiler and imposes the same restrictions, but requires no parallelization directives

from the user. The run-time environment is based on simple synchronization primitives and is implemented using Mach threads. We report the speedups of several compiled programs running on RP3 under the Mach operating system. The current implementation exploits only data parallelism. We discuss the relationship between the style of an APL program and its expected benefit from the automatic parallel execution provided by our compiler.

Automatic partitioning of a program dependence graph into parallel tasks *by V. Sarkar, p. 779.* In this paper, we describe a general interprocedural framework for partitioning a program dependence graph into parallel tasks for execution on a multiprocessor system. Partitioning techniques are necessary to execute a parallel program at the appropriate granularity for a given target multiprocessor. The problem is to determine the best trade-off between parallelism and overhead. It is desirable for the partitioning to be performed automatically, so that the programmer can write a parallel program without being burdened by details of the overhead target multiprocessor, and so that the same parallel program can be made to execute efficiently on different multiprocessors. For each procedure, the partitioning algorithm attempts to minimize the estimated parallel execution time. The estimated parallel execution time reflects a trade-off between parallelism and overhead and is minimized at an optimal intermediate granularity of parallelism. Execution-profiling information is used to obtain accurate execution-time estimates. The partitioning framework has been completely implemented in the PTRAN system at the IBM Thomas J. Watson Research Center. Partitioned parallel programs generated by this prototype system have been executed on the IBM 3090™ and RP3 multiprocessor systems.

Monitoring the performance of commercial T1-rate transmission service *by D. R. Irvin, p. 805.* This paper gathers the scattered empirical and theoretical elements of the performance-management problem for commercial T1-rate transmission service and integrates these elements in a useful way. We propose two variants of a time-based performance-monitoring algorithm that are insensitive to the arrival pattern of transmission errors. The first variant compares a count of errored seconds accumulated over an interval of time to a fixed threshold, and issues an alert to the network operator indicating degraded transmission performance whenever the count exceeds the threshold before the measurement interval expires. The fixed-threshold test is calibrated with reference to the well-known Neyman model of transmission errors on metallic-conductor systems. This calibration is then shown to be suitable as well for monitoring the performance of fiber-optic transmission systems where errored seconds follow the cumulative binomial distribution. The second variant of the new performance-monitoring algorithm replaces the fixed-threshold test with a dual-threshold test having a lower threshold that remains fixed and a higher threshold that floats in response to changes in error characteristics. An analysis based on the difference equations that describe the movement of the floating threshold shows that the dual-threshold test is more responsive than the fixed-threshold test in detecting nonstationary trends toward degraded transmission and in detecting stable but mediocre performance levels.

A trace-driven study of CMS file references *by G. P. Bozman, H. H. Ghannad, and E. D. Weinberger, p. 815.* This paper presents a detailed study of file reference patterns by users of a VM/CMS interactive system. The data were collected from two different IBM locations via CMON, a CMS monitoring facility. We present background information about the CMS file system, the CMON program, and our data-reduction programs, as well as a discussion of the results. Some earlier studies of this type have been restricted to a static analysis of the existing files. However, as is shown in this paper, a static analysis does not reliably reflect dynamic file reference behavior. By using both static statistics and dynamic statistics, it is possible to better understand how file systems are used, to evaluate possible changes, and to provide distribution parameters for modeling. More recent studies of other interactive systems have measured dynamic activity patterns. We compare our results with these when appropriate.

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Preface *by J. C. McGroddy, p. 2.*

Thin-film-transistor/liquid crystal display technology—An introduction *by W. E. Howard, p. 3.* Liquid crystals are simple and very efficient electro-optic transducers, or light valves. Thin-film transistors are simple electronic control devices which can be fabricated on large transparent substrates. These two technologies, when combined, allow the fabrication of electronic displays which challenge the dominance of the cathode ray tube (CRT). This paper reviews the history of this important development, presents the current status in comparison to the color CRT, and describes the remaining challenges to be overcome if the color CRT is truly to be displaced.

A gray-scale addressing technique for thin-film-transistor/liquid crystal displays *by P. M. Alt, C. G. Powell, B. L. Owens, Jr., and H. Ifill, p. 11.* An addressing technique allowing continuous-tone color images to be rendered on thin-film-transistor/liquid crystal displays having bilevel drivers is described. The technique uses multiple subfields per frame, with driver voltages changed synchronously with the field data. By using N bits of data per pixel, excitation is applied to the display one bit-plane per field for N consecutive fields. The technique is analyzed, its benefits and limitations discussed, and experimental results presented. Up to 16 gray levels have been demonstrated with good image quality.

Cell design of gray-scale thin-film-transistor-driven liquid crystal displays *by H. Takano, S. Suzuki, and H. Hatoh, p. 23.* The desirable liquid crystal (LC) panel design (here called "cell design") for a gray-scale thin-film-transistor (TFT) -driven twisted nematic (TN) liquid crystal display (LCD) is discussed in terms of display legibility and ease of fabrication. To optimize cell design for gray-scale application, some key display factors such as contrast ratio, color change, and viewing cone are evaluated for various cell geometries and cell thicknesses. The cell geometries discussed are combinations of two display modes (a normally white mode and a normally black mode, in which the optical axes of the exit polarizers are placed perpendicular and parallel to those of the entrance polarizers, respectively) and two optical eigenmodes (an extraordinary-ray mode and an ordinary-ray mode, in which the transmission axes of the entrance polarizers are parallel and perpendicular to the entrance rubbing directions, respectively). A new driving scheme of threshold-voltage bias application to the LC cell is proposed to overcome the TN LCD shortcoming of a narrow viewing cone. We have adopted a cell design for a 512-color TFT LCD: 1) a first minimum normally white (NW) mode as polarizer arrangement for ease of fabrication, 2) an extraordinary-ray mode (e-mode) as optical eigenmode with a novel driving scheme (threshold-voltage biased) for gray-scale improvement in eliminating brightness reversals, and 3) a retardation ($d\Delta n$) value of 0.47 μm for further optimization of proper gray-scale order and color change. We have called this mode "threshold-voltage-biased e-mode NW," or "biased e-mode NW."

Color filter for 10.4-in.-diagonal 4096-color thin-film-transistor liquid crystal displays *by T. Koseki, T. Fukunaga, H. Yamanaka, and T. Ueki, p. 43.* Color filters with a wide color reproduction gamut and high transmittance were developed for 10.4-in.-diagonal 4096-color thin-film-transistor liquid crystal displays using pigment-dispersed photosensitive polymers. The transmission spectrum of each color pixel was designed in conjunction with other components such as backlight and polarizers in order to meet front-of-screen quality requirements. To improve screen quality, a low-resistivity common electrode was used, eliminating the top coating. A repair technique utilizing back-exposure was also developed to improve production yield. This pigment-dispersed-type color filter has the merits of a simple process, low fabrication cost, good uniformity, high reliability, and applicability to high-resolution displays. There is a problem involving deterioration of contrast ratio caused by the depolarization effect of the color filter. We measured depolarization factors for several pigments and showed that the yellow pigment was the major contributor. This depolarization effect has been minimized.

Lateral field effect in twisted nematic cells *by A. Lien and R. A. John, p. 51.* The lateral field existing in the ON state of a liquid crystal display (LCD) can result in an undesired reverse tilt domain in each pixel, thereby leading to poor contrast ratio of the display. As pixel size becomes smaller to meet the requirements of a high-information-content display, the problem becomes worse. In this paper, we present experimental results and theoretical analysis of the lateral field effect in the twisted nematic (TN) cell, which is most commonly used in the thin-film-transistor liquid crystal displays (TFT/LCD). The effects of various cell parameters, such as pretilt angle, bus-line-to-pixel spacing, and cell gap thickness, on the pixel reverse tilt domain and on the corresponding optical performance have been studied in detail. The results are useful for TFT/LCD design and cell fabrication.

Functional testing of TFT/LCD arrays *by L. C. Jenkins, R. J. Polastre, R. R. Troutman, and R. L. Wisnieff, p. 59.* The thin-film-transistor liquid crystal display (TFT/LCD) is emerging as the leading flat-panel display in computer applications. TFT array characterization is important to the research, development, and manufacturing of TFT/LCDs. This paper describes a new Dynamic Array Tester developed for that purpose and describes some examples of its use.

Reactive ion etching technology in thin-film-transistor processing *by Y. Kuo, p. 69.* This paper discusses reactive ion etching (RIE) process issues in preparing thin-film transistors (TFTs) for liquid crystal displays (LCDs). Three areas were

examined in detail: gate metal etch, dielectric etch, and a-Si:H etch, both intrinsic and n^+ doped. Although there are different requirements for each step, the basic principles for the etching process are similar. For example, each process includes three major mechanisms: plasma-phase chemistry, particle transport phenomena, and surface reactions. All data on the etching results were interpreted according to these principles. Finally, a TFT characteristic curve based on RIE of some of the most critical process steps is presented.

Study of the V_{th} shift of the thin-film transistor by the bias temperature stress test *by Y. Fujimoto, p. 76.* Amorphous silicon thin-film transistors (a-Si:H TFTs) are now widely used as the switching device in the active-matrix addressing of liquid crystal displays. One concern is the potential instability problems associated with the threshold voltage (V_{th}) shifts to higher values after prolonged operating times. The reason for this V_{th} shift has been widely discussed, and two models accounting for it have been suggested. One model explains the shifts by the trapping of electrons in the insulator, the other model by the creation of the metastable states at the a-Si:H/SiN_x interface. Our TFT insulator has the rather complicated structure of an anodic oxide film, SiO_x, SiN_x sequentially stacked over the gate electrode, which makes it difficult to separate the contribution of each layer. To confirm the V_{th} shift mechanism and the contribution of each layer of insulator to the V_{th} shift, we have prepared samples with a series of different insulators and have measured the bias dependence of their V_{th} shifts. Our results show that the anodic oxide film makes no contribution to the V_{th} shift, and it makes little difference to the V_{th} shift whether the next insulator is SiN_x or SiO_x. The latter fact may be explained in two ways. One is that both SiN_x and SiO_x make the same contribution to the V_{th} shift. Alternatively, neither SiN_x nor SiO_x makes any contribution to the V_{th} shift, but the a-Si:H/gate insulator interface has some contribution. From these experiments, it cannot be determined which of the proposed mechanisms is consistent with the behavior of the V_{th} shift of our a-Si:H TFT.

TDI charge-coupled devices: Design and applications *by H.-S. Wong, Y. L. Yao, and E. S. Schlig, p. 83.* The design and applications of charge-coupled devices (CCDs) operated in the time-delay-and-integration (TDI) mode are reviewed. Design issues regarding the use of the TDI-CCD imager for visible imaging applications are discussed. Aspects pertaining to its parallel array, serial-to-parallel interface, serial register, modulation transfer function (MTF), discrete charge motion, motion synchronization, clocking, number of integrating stages, noise, dynamic range, sensitivity, output uniformity, device yield, pixel size, and spectral response are highlighted in the context of their effect on system performance. Its imaging characteristics are compared to those of the photodiode linear array imager, and design studies and experimental results for a family of TDI-CCD imagers for scanning documents and museum art objects are described.

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Preface *by N. O. Lipari, p. 138.*

Plasma-based dry etching techniques in the silicon integrated circuit technology *by G. S. Oehrlein and J. F. Rembetski, p. 140.* Plasma-based dry etching techniques play a major role in the formation of silicon-based integrated circuits. The first part of this paper reviews our understanding of the means for achieving etching directionality and selectivity in reactive etching using glow discharges. Relevant trends in magnetically enhanced rf diode systems, microwave-excited electron cyclotron resonance plasmas, process clustering, real-time process monitoring and control, and computer modeling of glow discharges are discussed in the second part of the paper.

Stress-induced dislocations in silicon integrated circuits *by P. M. Fahey, S. R. Mader, S. R. Stiffler, R. L. Mohler, J. D. Mis, and J. A. Slinkman, p. 158.* Many of the processes used in the fabrication of silicon integrated circuits lead to the development of stress in the silicon substrate. Given enough stress, the substrate will yield by generating dislocations. We examine the formation of stress-induced dislocations in integrated circuit structures. Examples are presented from bipolar and MOS-based integrated circuit structures that were created during developmental studies. The underlying causes of oxidation-induced stress and the effect on such stress of varying oxidation conditions are discussed. The knowledge thus gained is used to explain dislocation generation during the formation of a shallow-trench isolation structure. The importance of ion-implantation processes in nucleating dislocations is illustrated using structures formed by a deep-trench isolation process and a process used to form a trench capacitor in a DRAM cell. The effect of device layout geometry on dislocation generation is also examined. We show how TEM observations can be used to provide more information than solely identifying those process conditions under which dislocations are generated. By combining TEM observations with stress analysis, we show how the sources of stress responsible for dislocation movement can be identified.

Application of electron and ion beam analysis techniques to microelectronics *by T.-S. Kuan, P. E. Batson, R. M. Feenstra, A. J. Slavin, and R. M. Tromp, p. 183.* The application of electron microscopy, scanning tunneling microscopy, and medium-energy ion scattering to microelectronics is reviewed. These analysis techniques are playing an important role in advancing the technology. Their use in the study of relevant phenomena regarding surfaces, interfaces, and defects is discussed. Recent developments and applications are illustrated using results obtained at the IBM Thomas J. Watson Research Center. Potential advances in the techniques are also discussed.

Numerical modeling of advanced semiconductor devices *by W. Lee, S. E. Laux, M. V. Fischetti, G. Baccarani, A. Gnudi, J. M. C. Stork, J. A. Mandelman, E. F. Crabbé, M. R. Wordeman, and F. Odeh, p. 208.* Numerical modeling of the electrical behavior of semiconductor devices is playing an increasingly important role in their development. Examples that pertain to advanced MOSFETs and bipolar transistors are presented to illustrate the importance of taking into account three-dimensional as well as nonequilibrium and nonlocal physical phenomena to effectively characterize the electrical behavior of such devices.

Integrated processing for microelectronics science and technology *by G. W. Rubloff and D. T. Bordonaro, p. 233.* This paper is a review of integrated processing—an approach to microelectronics fabrication in which sequential processes are linked by wafer transfer through a clean, controlled environment (e.g., high vacuum or inert gas). The approach is rapidly becoming the state of the art in microelectronics research, development, and manufacturing. In microelectronics research, it provides a means for advancing mechanistic understanding and material quality through *in situ* fabrication of test structures and extensive *in situ* diagnostics. In microelectronics development and manufacturing, it promises process simplification, improved contamination control and yield, and potentially more flexible equipment utilization. With increasing emphasis on ultraclean processing, involving control of reactive impurities as well as particles, and on real-time process monitoring and control, applications of integrated processing are moving toward a common ground in which state-of-the-art research techniques can be used to address key issues in development and manufacturing, and provide in return substantive guidelines for manufacturing design and practice.

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Preface *by J. H. Griesmer, p. 328.*

Arthur Samuel: Pioneer in Machine Learning *by G. Wiederhold and J. McCarthy, p. 329.*

Capturing the deep meaning of texts through deduction and inference *by F. Antonacci and C. M. Calamani, p. 333.* One of the main problems in the computer analysis of natural language is understanding sentences beyond a surface level, i.e., making inferences about likely circumstances and drawing plausible conclusions. At the first level, a natural-language-understanding system can answer simple and trivial questions; in order to extend the domain of possible questions that it can answer, the system must make presuppositions and recognize implications that depend on certain events (also called actions). The IBM Rome Scientific Center has developed a prototype system that is able to make inferences about what might be true. This system has been integrated with a text-understanding system (System N), also developed at Rome.

Explaining SLDNF resolution with non-normal defaults *by M. A. Casanova, A. S. Hemerly, and R. A. de T. Guerreiro, p. 347.* This paper defines a default logic interpretation for normal programs that has the following major characteristics. First, it directly captures the true nature of SLDNF resolution as an extension of SLD resolution. Second, it is semantically convincing, but it requires neither an elaborated nonstandard interpretation nor a radical rewriting of the program clauses that would make it difficult to understand their meaning. Last, it extends known results for stratified normal programs to programs that satisfy a weaker condition.

STORK and PENGUIN: Logic programming systems using general clauses and defaults *by R. A. de T. Guerreiro, A. S. Hemerly, and M. A. Casanova, p. 361.* This paper describes two logic programming systems with the expressive power of full clausal first-order logic and with a nonmonotonic component. They provide a direct generalization of pure Prolog and can be implemented using the same technology as Prolog processors. The inference engine of both systems is based on the weak-model elimination method which, in the case of the second system, is extended to incorporate defaults.

Logic programming with typed unification and its realization on an abstract machine *by C. Beierle, p. 375.* Logic programming can benefit from a typing concept which supports many software engineering principles such as data abstraction, modularization, etc. From a computational point of view, the use of types can drastically reduce the search space. Starting from these observations, this paper gives a survey of many-sorted, order-sorted, and polymorphic approaches to type concepts in logic programming. The underlying unification procedures for ordinary term unification, order-sorted unification, and in particular for polymorphic order-sorted unification are given in the style of solving a set of equations, giving a common basis for comparing them. In addition, the realization of these unification procedures on a Warren Abstract Machine-like architecture is described. Special emphasis is placed on the abstract machine developed for PROTOS-L, a logic programming language based on polymorphic order-sorted unification.

Zephyr: Toward true compiler-based programming in Prolog *by Y. Asakawa, H. Komatsu, H. Etoh, Y. Hama, and K. Maruyama, p. 391.* Prolog is widely used in prototyping, especially in artificial intelligence, but it has yet to gain widespread acceptance in application development. We think that the problems in this area result from the programming style enforced in existing Prolog systems. Zephyr is a new Prolog system refined and enhanced to help solve such problems. It allows users to do modular programming by always using a compiler instead of an interpreter. In this paper, we describe the unique features of Zephyr which make

this possible, focusing especially on *package, metafunctions,* and *tables,* and the implementation of the system on OS/2.®

An experiment in constructing an open expert system using a knowledge substrate *by C. V. Apté, R. A. Dionne, J. H. Griesmer, M. Karnaugh, J. K. Kastner, M. M. Laker, and E. K. Mays, p. 409.* This paper discusses an experiment in the use of an object-centered knowledge representation service to provide a common conceptual model for the construction of a large knowledge-intensive decision support tool. A core knowledge substrate forms a common resource for a variety of problem-solving activities and a basis for the rapid construction of new capabilities. FAME, a substantial expert system to aid in the financial marketing of IBM mainframes, has been built and extensively tested in the field to validate our tools and techniques.

Use of natural language for knowledge acquisition: Strategies to cope with semantic and pragmatic variation *by T. Wetter and R. Nüse, p. 435.* The large amount of verbal data from common knowledge-elicitation methods suggests using the data directly for knowledge acquisition by means of sophisticated natural-language analyzers (NLAs). In this paper, we analyze the feasibility of such an approach theoretically and present a number of examples. In the theoretical part of the text we first provide a detailed analysis of the *entities* involved, i.e., the domains of expertise, the qualities of knowledge about domains, the properties of generic sentences and texts in natural languages, and the conclusions to be drawn from the limited expressiveness of formal representations. Then we discuss the *processes* of transforming knowledge into natural language and of transforming natural language into formal language. Since much can go wrong in both processes, we derive desired relations or *validity criteria* among the entities and *strategies* to meet the criteria. We believe that this broad theoretical framework can be used to analyze and compare existing attempts at directly using natural language for knowledge acquisition, and thus assess the present status of the field.

Topological reasoning about dextrous grasps *by T. N. Nguyen and H. E. Stephanou, p. 469.* The need, in robot manipulation, for higher levels of dexterity and versatility than those provided by grippers and by special-purpose end-effectors has prompted much research effort during the last decade on the design and control of multifingered hands. Most work on multifingered robot hands has dealt with low-level, numeric control, commonly based on screw theory and tools drawn from line geometry, differential geometry, kinematics, and dynamics. Current numeric, contact-based schemes, however, are limited to tip prehension (intentional grasping by the fingertips). The intriguing ease with which humans perform grasping and manipulation activities has concurrently triggered new investigations to provide robots with humanlike, prehensile capability for complex tasks in unstructured environments. These investigations have resulted in numerous AI-oriented, task-directed, distributed, symbolic schemes that have been conducted essentially independently. Efforts to link symbolic and numeric schemes have been undertaken, but the results have been rather modest. This paper deals with an intelligent, integrated symbolic-numeric scheme for dextrous manipulation, using a topological approach. In this paper, we introduce a reasoning scheme called topological reasoning that is used in conjunction with a grasp-based, topological model for uniform representations of multifingered robot hands at different levels of detail (e.g., whole hand, finger, joint), and discuss its application to dextrous manipulation (grasp selection and regrasping). We show that using topological reasoning, both hand posture and hand functionality can be derived from symbolic, high-level task requirements and object attributes, and can be transformed into numeric, low-level, joint space variables. Furthermore, the reasoning scheme is applicable not only to tip prehension, but also to palm prehension and any combination of the two.

Optical recognition of hand-printed characters of any size, position, and orientation *by S. Di Zenzo, M. Del Buono, M. Meucci, and A. Spirito, p. 487.* This paper deals with the optical recognition of text data in documents such as engineering drawings, land-use and land-register maps, and utility maps. The automatic computer acquisition of these documents is performed through the basic steps of vectorization of the line-structure and recognition of the text data interspersed in the document. The latter data are usually handwritten by professional draftsmen, and may have any size, position, and orientation. We review some of the features appropriate to this particular OCR problem, and suggest a special recognition strategy. Numerous examples are given. The results obtained with a prototype system on actual land-register maps are reported.

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Preface *by N. M. Donofrio, p. 533.*

Enterprise Systems Connection (ESCON) Architecture—System overview *by S. A. Calta, J. A. deVeer, E. Loizides, and R. N. Strangwayes, p. 535.* This paper serves as an introduction to a wholly new IBM data processing interconnection system called Enterprise Systems Connection (ESCON™) Architecture™. Utilizing state-of-the-art fiber optic technology, the ESCON system introduces a unique concept to computer interconnection topology, the dynamic switched point-to-point connection. A comprehensive solution to the interconnection of data processing equipment and systems, the ESCON system offers superior connectivity, bandwidth, distance, and ease of installation. The ESCON architecture is directed toward the structuring of large dispersed multisystem data processing centers with campus distributed user communities, but it is equally well suited to the needs of small processing configurations. The paper first reviews the objectives of the ESCON development and then gives a more detailed discussion of the system design

alternatives and choices which were made. Topics discussed are the fiber optic technology, the interconnection topology, the ESCON architecture, and the design of the major system elements.

IBM Enterprise Systems multimode fiber optic technology *by N. R. Aulet, D. W. Boerstler, G. DeMario, F. D. Ferraiolo, C. E. Hayward, C. D. Heath, A. L. Huffman, W. R. Kelly, G. W. Peterson, and D. J. Stigliani, Jr., p. 553.* This paper describes the first implementation of optical fiber technology for the I/O channel connections of the IBM Enterprise Systems Connection (ESCON™) Architecture™. The ESCON optical link line rate is 200 megabits per second and is capable of transmission over distances of 3 km. The link is composed of a serializer, electro-optic transmitter, duplex fiber optic cable, electro-optic receiver, and deserializer. The serializer and deserializer respectively perform the conversions from parallel to serial and serial to parallel formats. The clock which is used to retime the serial data in the deserializer is extracted from the encoded serial signal using a phase-locked loop (PLL) technique. The optical link technology selected to achieve the data processing system requirements is InGaAsP/InP 1300-nm LED, InGaAsP/InP PIN photodiode, and multimode optical fiber. A duplex fiber jumper cable is designed with a rugged, low-profile, polarized connector, with a unique protective cap which recedes as it is mated. The optical link loss budget is determined by dividing the link into two major categories: available optical power and cable plant loss. The link design ensures that the minimum available power is greater than the maximum cable plant loss. The design parameters and trade-offs of the optical link are discussed in this paper. Unique measurement techniques and tools to ensure reliable and consistent link performance are described.

The IBM Enterprise Systems Connection (ESCON) Architecture *by J. C. Elliott and M. W. Sachs, p. 577.* The IBM Enterprise Systems Connection (ESCON™) Architecture™ is the architecture for the new fiber optic serial-I/O channels for the processors in the IBM System/390® family. The architecture is based on message exchanges, which replace the byte-oriented protocols of the predecessor parallel interface architecture. Its interconnection topology employs a dynamic crosspoint switch. This paper describes the major functional components of the architecture and discusses some of the technical problems that were solved during its development.

The IBM Enterprise Systems Connection (ESCON) Director: A dynamic switch for 200Mb/s fiber optic links *by C. J. Georgiou, T. A. Larsen, P. W. Oakhill, and B. Salimi, p. 593.* This paper describes the function and hardware structure of the Enterprise Systems Connection (ESCON™) Director™, an I/O switch capable of providing dynamic, nonblocking, any-to-any connectivity for up to 60 fiber optic links operating at 200 Mb/s. Optoelectronic conversion at the switch ports allows the switching of the fiber optic links to be done electronically. The establishment of paths in the switching matrix is done by means of a hard-wired, pipelined controller at a maximum rate of five million connections/disconnections per second. Routing information is provided in the header of data frames. The switch-port function, switching matrix, and matrix controller were implemented in the IBM 1-μm CMOS "standard cell" technology. The paper discusses the system interconnection philosophy, details of the data flow, the switch hardware architecture, the design methodology, and the approach to technology implementation.

The IBM Enterprise Systems Connection (ESCON) channel—A versatile building block *by J. R. Flanagan, T. A. Gregg, and D. F. Casper, p. 617.* The IBM Enterprise Systems Connection (ESCON™) environment required the design of a single channel that could be attached to the entire line of Enterprise System/9000™ processors and deliver the performance required by the top of that line. In addition to the channel, other functions were needed, such as the ESCON channel-to-channel adapter. All of these functions were required to be implemented using the same channel hardware. This paper describes the key elements of the IBM ESCON channel design.

MVS Dynamic Reconfiguration Management *by R. Cwiakala, J. D. Haggar, and H. M. Yudenfriend, p. 633.* This paper presents an overview of the Dynamic Reconfiguration Management (DRM) function of MVS/ESA™ and its support of the IBM Enterprise System/9000™ family of machines. Dynamic Reconfiguration Management is the ability to select a new I/O configuration definition without needing to perform a power-on reset (POR) of the hardware or an initial program load (IPL) of the MVS operating system. Dynamic Reconfiguration Management allows the installation to add, delete, or modify definitions for channel paths, control units, and I/O devices, in both the software and hardware I/O configurations.

Fiber Distributed Data Interface attachment to System/390 *by J. J. Coleman, C. B. Meltzer, and J. L. Weiner, p. 647.* IBM has articulated a commitment to open systems. An important element in this direction is connectivity based upon pervasive industry standards. A fundamental standard that enables System/390® to participate in heterogeneous systems environments is the Fiber Distributed Data Interface (FDDI), defined by ANSI. The initial IBM offering in support of FDDI is attachment to System/390 machines via the 3172 Interconnect Controller. FDDI provides a high-performance alternative to lower-speed local area networks (LANs) for attachment of workstations to System/390 mainframes. A key feature of the 3172 Micro Channel® (MC) controller is its internal bus structure, derived from PS/2® technology. The 3172 FDDI adapter is capable of data rates up to 80 megabytes per second (MBps). This should be sufficient to support multiple FDDI LANs at their rated speed of 10 MBps. Also, because of its MC orientation, the 3172 FDDI adapter

is potentially extendable to other platforms derived from PS/2 and RISC System/6000® technology.

Coordination of time-of-day clocks among multiple systems *by N. R. Dhondy, R. J. Schmalz, R. M. Smith, Sr., J. Thomas, and P. Yeh, p. 655.* The IBM Enterprise Systems Architecture/390™ External-Time-Reference (ETR) architecture facilitates the synchronization of time-of-day (TOD) clocks to ensure consistent time-stamp data in an installation with multiple systems. The ETR architecture also provides a means by which the TOD clocks can be set automatically, without human intervention, to an accurate standard time source. This paper reviews the design considerations involved in providing these functions—along with "clock integrity" and continuous operation—as a consistent extension of the System/370™ TOD-clock architecture. The paper also provides a functional description of the IBM 9037 Sysplex Timer®, which is an implementation of the sending unit of the ETR network.

MVS/ESA coupled-systems considerations *by M. D. Swanson and C. P. Vignola, p. 667.* One of the most important future MVS environments will be to provide on-line transaction processing and decision support through the use of large data "warehouses" in heterogeneous networks. To provide the large capacity and high availability required for this environment, it will be necessary to use multiple, cooperating MVS systems to provide those services. The design of such coupled MVS systems must accommodate a number of factors related to both the general environment and the user's needs, including availability, growth, granularity and scale, systems management, migration and coexistence, and single-system images. In this paper, we describe the system services available with MVS/ESA™ SP Version 4 that can support the coupled-systems environment, and discuss how those services can be exploited.

Integrated Cryptographic Facility of the Enterprise Systems Architecture/390: Design considerations *by R. M. Smith, Sr. and P. C. Yeh, p. 683.* This paper reviews the considerations that shaped the design of the Enterprise Systems Architecture/390™ Integrated Cryptographic Facility. It describes design issues, alternatives, and decisions, and it provides the rationale behind some of the decisions. Issues related to performance, security, usability, and availability are covered.

Design of the IBM System/390 computer family for numerically intensive applications: An overview for engineers and scientists *by D. H. Gibson and G. S. Rao, p. 695.* The IBM System/390® (S/390) computer family provides a two-order-of-magnitude performance range for numerically intensive applications. The engineer or scientist can use the same operating system, compiler, and run-time environment commonly across the family. This paper provides an overview of primary S/390 hardware and software products of interest for numerically intensive applications, including MVS/ESA™, VM/ESA®, AIX/ESA™, and the extension of FORTRAN for very large applications and parallel applications. The primary portion of the paper is focused on details of design interest in three specific hardware products within the S/390 family, with emphasis on the Enterprise System/9000™ (ES/9000™) Model 900. Also described is a potential parallel-computing configuration using the ESCON Director™. The paper concludes with a discussion of the generic system environments within which S/390 products can support the technical user.

Design of the IBM Enterprise System/9000 high-end processor *by J. S. Liptay, p. 713.* The "high-end" water-cooled processors in the IBM Enterprise System/9000™ product family use a CPU organization and cache structure which depart significantly from previous designs. The CPU organization includes multiple execution elements which execute instructions out of sequence, and uses a new virtual register management algorithm to control them. It also contains a branch history table to remember recent branches and their target addresses so that instruction fetching and decoding can be directed more accurately. These models also use a two-level cache structure which provides a level 1 cache associated with each processor and a level 2 cache associated with central storage. The level 1 cache uses a store-through organization, and is split into two separate caches, one used for instruction fetching and the other for operand references. The level 2 cache uses a store-in method to handle stores.

A single-chip IBM System/390 floating-point processor in CMOS *by S. Dao-Trong and K. Helwig, p. 733.* A floating-point processor with the IBM System/390® architecture is implemented in one CMOS VLSI chip containing over 70,000 cells (equivalent inverters), using a transistor channel length of 0.5 μm. All floating-point instructions are hard-wired, including the binary integer multiplications. The chip is implemented in a 1-μm technology with three layers of metal. All circuits are realized in standard cells except for a floating-point register and a multiplier array macro, which are custom designed to save chip area. Instructions are performed in a five-stage pipeline with a maximum operating frequency of 37 MHz. The chip measures 12.7 mm × 12.7 mm, and dissipates 2 W. It is part of the chip set which forms the core of the IBM Enterprise System/9000™ Type 9221 entry-level models.

Simulation of IBM Enterprise System/9000 Models 820 and 900 *by D. F. Ackerman, M. H. Decker, J. J. Gosselin, K. M. Lasko, M. P. Mullen, R. E. Rosa, E. V. Valera, and B. Wile, p. 751.* The discovery and removal of logic design errors early in the development cycle is critical to timely availability of market-driven processor products. This paper describes the part played by simulation in the verification of the high-end models of the IBM Enterprise System/9000™ (ES/9000™) processor family, and how that effort advanced the state of the art of logic design simulation. The increased complexity of

the ES/9000 design over that of the IBM Enterprise System/3090™ (ES/3090™) necessitated a larger simulation effort. New tools and methods were developed. Two simulation missions were established. Element simulation addressed ES/9000 functional elements (e.g., the storage controller) individually using the Compiled Enhanced Functional Simulator (CEFS), a software tool. System simulation tested two or more functional elements together using the Engineering Verification Engine (EVE), a special-purpose hardware parallel processor, and an attached IBM 3092 Processor Controller (PCE). The results achieved by simulation are discussed, together with the methods used and the impact these results had on the overall verification of the ES/9000 Models 820 and 900.

Fault-tolerance design of the IBM Enterprise System/9000 Type 9021 processors *by C. L. Chen, N. N. Tendolkar, A. J. Sutton, M. Y. Hsiao, and D. C. Bossen, p. 765.* The 9021-type processors offer the highest performance of the IBM Enterprise System/9000™ (ES/9000™) series. They also have the highest levels of concurrent error detection, fault isolation, recovery, and availability of any IBM general-purpose processor. High availability is achieved by minimizing component failure rates through improvements of the base technology, and design techniques that permit hard and soft failure detection, recovery and isolation, and component replacement concurrent with system operation. In this paper, we discuss fault-tolerant design techniques for array, logic, and storage subsystems. We also present diagnostic strategy, fault isolation, and recovery techniques. New features such as the redundant power system and Processor Availability Facility are described. The overall recovery design is described, as well as specific implementation schemes. The design process to verify the error detection, fault isolation, and recovery is also described.

Three-loop feedback control of fault-tolerant power supplies in IBM Enterprise System/9000 processors *by K. R. Covi, p. 781.* In an Enterprise System/9000™ (ES/9000™) processor, a fault-tolerant power system composed of multiple power supplies connected in parallel provides thousands of amperes of current to low-voltage (1–2 V) logic circuit boards, monitors the voltage at each board, and immediately responds to compensate for failure of a supply. If a supply fails, the very fast closed-loop response redistributes the current uniformity among the remaining supplies and allows the normal functioning of the processor logic to continue uninterrupted. This rapid response is not obtained from a conventional two-loop (current-mode) feedback power supply because the loop bandwidth is restricted by a resonance that develops in the power distribution. A third feedback loop that is added to each supply controls this power distribution resonance and makes possible the wide loop bandwidth necessary to achieve the required power system control. Analysis is presented of a three-loop control system, and a simulation of its application to a typical ES/9000 power system is described.

System cooling design for the water-cooled IBM Enterprise System/9000 processors *by D. J. Delia, T. C. Gilgert, N. H. Graham, U. Hwang, P. W. Ing, J. C. Kan, R. G. Kemink, G. C. Maling, R. F. Martin, K. P. Moran, J. R. Reyes, R. R. Schmidt, and R. A. Steinbrecher, p. 791.* The high operating speed and corresponding high chip heat fluxes in the IBM Enterprise System/9000™ water-cooled mainframe processors are made possible by improvements in component- and system-level cooling. The heart of the closed-loop water-cooling system is a coolant distribution frame (CDF) common to all water-cooled processors. The CDF provides a controlled water temperature of 21.7°C to the central electronic complex (CEC) at water flow rates up to 245 liters per minute (lpm) and rejects heat loads of up to 63 kW for the largest processor. The water flow provides cooling to multichip thermal conduction modules (TCMs), to power supplies, and to air-to-water heat exchangers that provide preconditioned air to channel and memory cards. As many as 121 chips are mounted on a TCM glass-ceramic substrate, with chip powers reaching 27 W or a heat flux of 64 W/cm^2. A separate cold plate was developed to cool these modules. The power supplies with high heat densities are primarily cooled by water which flows through a unique separable cold plate designed for ease of serviceability of the power supply. Although water cooling is utilized for components with high heat fluxes, air cooling is employed for elements of the system with lower power densities. For cards cooled by forced air, careful trade-off studies among acoustical power, chip reliability, and high availability were required. The acoustic noise emissions of all the fans and blowers were determined, and a system model was constructed to measure the noise radiated from each frame in the system. The data were used to design top covers and other components to ensure that the system could meet its thermal/acoustical requirements. A closed-loop frame in which all the heat was rejected to water was developed to meet these requirements.

Dual-tapered-piston (DTP) module cooling for IBM Enterprise System/9000 systems *by G. F. Goth, M. L. Zumbrunnen, and K. P. Moran, p. 805.* The water-cooled thermal conduction modules (TCMs) in the IBM Enterprise System/9000™ (ES/9000™) systems require a fourfold thermal improvement over TCMs in the 3090™ system. An examination of the thermal/mechanical tolerance relationships among the chips, substrate, and cooling hardware showed that a cylindrical piston would not meet this requirement. The piston was redesigned with a cylindrical center section and a taper on each end. This shape minimizes the gap between the piston and "hat" while retaining intimate contact between the piston face and chip surface during all assembly conditions. Numerical and analytical models demonstrate that this new piston shape, coupled with improved conductivity of the cooling hardware materials, exceeds ES/9000 system needs. These models were verified by tests conducted on single-site and full-scale modules in the laboratory and by tests on actual ES/9000 systems.

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Preface *by M. J. Attardo, p. 819.*

Advancing the state of the art in high-performance logic and array technology *by K. H. Brown, D. A. Grose, R. C. Lange, T. H. Ning, and P. A. Totta, p. 821.* High-speed silicon bipolar technology continues to meet the demands of integrated circuits for mainframe computers. IBM has developed an advanced bipolar logic and high-speed array technology for its Enterprise System/9000™ systems. This technology, code-named ATX-4, is composed of trench-isolated, double-polysilicon self-aligned bipolar devices, and has four fully planarized wiring levels with interlevel connecting studs. Chip fabrication has been implemented in 1-μm ground rules and is in full-scale manufacturing. ATX-4 represents a significant advance in providing higher-speed and lower-power logic at increased levels of integration compared with that of the ATX-1 technology used in previous generations. An overview of the design and integration of ATX-4 is discussed.

Improved performance of IBM Enterprise System/9000 bipolar logic chips *by A. E. Barish, J. P. Eckhardt, M. D. Mayo, W. A. Svarczkopf, and S. P. Gaur, p. 829.* The performance required for logic gate arrays by the IBM Enterprise System/9000™ (ES/9000™) family of water-cooled processors was obtained by redesigning chips that previously consisted of emitter-coupled logic (ECL) circuits. Multiple bipolar logic circuit families were implemented for the first time on a single IBM chip by using a modular cell approach. In 60% of the ECL circuits, ac coupling in ECL gates reduced the maximum operating power per ECL circuit on ES/9000 chips by 50% and decreased the signal delay per loaded gate by 30%, to 150 ps. About 10–20% of the remaining ECL circuits were replaced by differential current switches (DCS) which dissipated less power and improved the overall chip performance. Circuits to communicate between ECL and DCS circuit families and to improve DCS circuit reliability were included on the ES/9000 chips without affecting logic function density.

A statistical approach to quality control of non-normal lithographical overlay distributions *by R. M. Booth, Jr., K. A. Tallman, T. J. Wiltshire, and P. L. Yee, p. 835.* To achieve the high reliability and performance required by integrated circuit (IC) chips in IBM Enterprise System/9000™ processors, lithography tool centerline overlay variations between masking levels were specified at ± 0.3 μm, and circuit design images were transferred with 5× step-and-repeat photolithography tools. In contrast to data obtained from 1× lithography tools, the level-to-level overlay data which characterize deviations from circuit design rules did not fit a normal distribution, and quality control was not achieved with traditional statistical procedures. A methodology was empirically developed which transformed measured data into worst-case overlay points and approximated the data by a gamma distribution. More than 80% of the worst-case distributions were fit by the gamma distribution. The transformation of chip worst-case overlay data and the quality control testing applicable to 5× step-and-repeat lithography tool processes are described in this paper.

A four-level VLSI bipolar metallization design with chemical–mechanical planarization *by W. L. Guthrie, W. J. Patrick, E. Levine, H. C. Jones, E. A. Mehter, T. F. Houghton, G. T. Chiu, and M. A. Fury, p. 845.* A high-performance four-level semiconductor device wiring fabrication process has been developed for bipolar devices in Enterprise System/9000™ (ES/9000™) processors. The reliable interconnection of large numbers of devices on a single integrated circuit chip has been enhanced by planarizing insulators and metals using chemical–mechanical polishing processes, by a novel contact stud structure, and by a Ti-clad Al–Cu metallurgy. This paper describes the structure of the four-level wiring and elements of the process, including the silicon contacts, techniques for depositing metal and oxide to cover features with high aspect ratios, high-temperature fine-line lift-off stencils, and high-density, area array solder terminals.

Directory and Trace memory chip with active discharge cell *by P. Bunce, W. Chin, L. Clark, and B. Krumm, p. 859.* The Directory and Trace memory chip is a 7.1Kb static random-access memory with 28-bit field simultaneous compare function and independent read and write 28-bit field addressing. The array is organized as four 64 by 28 subarrays. It incorporates a unique Schottky barrier diode (SBD)-coupled cell with active discharge. As memory cells are reduced in size with each new generation, soft errors become a major concern. One method of providing high soft-error immunity is to operate the memory cell transistors in the saturation region. However, in order to write data into such memory cells, the saturation capacitance in the memory cell transistors must be discharged. In prior art, such a capacitive transistor-saturation discharge was accompanied by increased power consumption and/or delay. Typically, the new data signals themselves are used to overcome this saturation capacitance. In this design a unique SBD-coupled active discharge cell discharges the conducting transistor saturation capacitance before writing new data into the cell. Thus, it enhances the write performance and preserves the high soft-error immunity of the cell.

IBM Enterprise System/9000 clock system: A technology and system perspective *by K. Chiu, J. J. DeFazio, and T. G. McNamara, p. 867.* The minimization of system clock skew is critical to the overall performance of high-speed computer systems. This paper discusses the statistical clock skew calculation methodology employed in the analysis of the IBM Enterprise System/9000™ (ES/9000™) computer systems. Comparisons made to a worst-case design approach show the advantages of a statistical clock skew calculation and its use in the timing analysis of ES/9000 systems. Design techniques

that aid in the minimization of system clock skew are discussed throughout this paper. While many details concerning these design techniques and the statistical clock skew calculation methodology are tutorial in nature and have been used in the design of past IBM high-end machines, it is hoped that this paper will give the reader a useful understanding of the major considerations affecting the clock system and its application to an ES/9000 system.

Physical and electrical design features of the IBM Enterprise System/9000 circuit module *by E. E. Davidson, P. W. Hardin, G. A. Katopis, M. G. Nealon, and L. L. Wu, p. 877.* The requirements of the new TCM (thermal conduction module) for the IBM Enterprise System/9000™ (ES/9000™) module generated a significant number of challenges for the physical and electrical designer. For example, the need to support more circuits meant that more signal and power conductors had to be provided. In addition, the requirement for faster performance called for materials with lower dielectric constants and the use of on-module decoupling capacitors. This paper describes these changes, the design considerations that were applied to signal transmission, and the approaches that were used to contain delta-*I* and crosstalk noise in the module. Finally, the test measurements used to qualify the module are explained. The result is a TCM that more than doubles the circuit density of the TCM used for the IBM 3090™ machines, with substantially greater speed and reliability.

High-performance glass-ceramic/copper multilayer substrate with thin-film redistribution *by R. R. Tummala, J. U. Knickerbocker, S. H. Knickerbocker, L. W. Herron, R. W. Nufer, R. N. Master, M. O. Neisser, B. M. Kellner, C. H. Perry, J. N. Humenik, and T. F. Redmond, p. 889.* IBM has pioneered the use of large-area alumina multilayer ceramic substrates using state-of-the-art greensheet, molybdenum paste, and tooling technologies for its mainframe computers since 1980. During this time, a new generation of substrate materials have been developed based on copper metallization and a unique glass that crystallizes to cordierite ($2Al_2O_3 \cdot 2MgO \cdot 5SiO_2$), which has a very low dielectric constant (5.0 compared to 9.4 in previous IBM systems). The glass-ceramic/copper system provides a factor of 3 improvement in electrical conductivity over alumina/molybdenum in previous IBM systems, and the number of metallized substrate layers has been increased from 45 to 63. The thermal expansion of the new substrate ($30 \times 10^{-7}°C^{-1}$) is matched with that of the silicon chips, thereby enhancing the reliability of the 78,500 solder-bonded chip-to-substrate connections in the System/390®–Enterprise System/9000™ computers. Each substrate is 127.5 mm square and can support up to 121 complex logic and memory chips. The IBM advanced multichip module dissipates more than twice the heat flux of previous alumina/multichip modules—to 17 W/cm^2 at the package level and 50 W/cm^2 at the chip level.

Equipment-related advances in the fabrication of glass-ceramic/copper/polyimide substrates *by J. R. Kranik, J. J. Fulton, L.-S. Su, and S. M. Zimmerman, p. 905.* This paper pertains to the equipment used to produce the multilayer glass-ceramic/copper/polyimide substrates of the thermal conduction modules (TCMs) used in the IBM Enterprise System/9000™ water-cooled processors. Discussed are a flexible equipment concept applied to the punching, inspection, and testing of the glass-ceramic/copper portion of the substrates, and laser-based equipment for ablation and repair of their polyimide/copper thin-film portion.

Electrical connections to the thermal conduction modules of the IBM Enterprise System/9000 water-cooled processors *by P. J. Brofman, S. K. Ray, and K. F. Beckham, p. 921.* In a complex multichip carrier such as the thermal conduction module (TCM) of IBM high-performance mainframe processors, the interfaces between chips and their substrate as well as between the substrate and its printed circuit board must support a large number of electrical connections. Since chip, substrate, and board typically comprise very different materials, the electrical connections between them must be able to accommodate considerable thermally induced mechanical stress during assembly and use. This paper describes the pin attachment, chip attachment, wire bonding, and laser deletion processes used for forming the electrical connections to the glass-ceramic/copper/polyimide /copper substrate of the thermal conduction modules of the IBM Enterprise System/9000™ water-cooled processors.

Low-inductance decoupling capacitor for the thermal conduction modules of the IBM Enterprise System/9000 processors *by J. N. Humenik, J. M. Oberschmidt, L. L. Wu, and S. G. Paull, p. 935.* Multilayer ceramic decoupling capacitors fabricated using a barium titanate-based dielectric are used with the glass-ceramic/copper/polyimide substrates of the thermal conduction modules (TCMs) of the IBM Enterprise System/9000™ processors to suppress the voltage noise generated by the logic circuits of the semiconductor chips used in the processors. Use is made of thick-film multilayer ceramic fabrication processes and thin-film termination processes to achieve substrate-mounted capabilities which, when combined with the low-inductance design of the capacitors, minimize the inductance of the decoupling paths to their adjacent chips. When mounted on the glass-ceramic/copper/polyimide substrate of a water-cooled TCM, the capacitors suppress approximately 50% of the voltage noise, thereby enhancing the performance of the TCMs.

Aspects of the electrical design and analyses of the printed circuit boards of the IBM Enterprise System/9000 water-cooled processors *by L. E. Boone, M. R. Brinthaupt, J. A. Malack, and J. Pavlik, p. 943.* Aspects of the electrical design and analyses of the multilayer printed circuit boards of the IBM Enterprise System/9000™ water-cooled processors are discussed. The design and analyses pertained to achieving

an increase in wirability and a decrease in voltage drops, power loss, simultaneous switching noise, variation in characteristic impedance, and reflections due to the presence of stubs.

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The controlled experiment in knowledge-acquisition research *by C. N. Nicholson, p. 958.* This paper is based on a review of the literature about controlled experiments in research on knowledge acquisition. The review was carried out to help the author make decisions about the design of his own experiment comparing two knowledge-acquisition methods. The paper looks critically at six experiments reported in the literature, and proposes a framework within which such empirical work can be viewed. It concludes that some of the apparent difficulties can be resolved, and that controlled experiments can be a useful way of discovering the relationships at work in a knowledge-acquisition project.

Knowledge in operation *by T. Bollinger and U. Pletat, p. 965.* The L_{LILOG} knowledge representation language and an inference engine to interpret it have been developed as part of the LILOG project, where new concepts for understanding natural-language texts were investigated. L_{LILOG} is a typed predicate logic whose type system has adopted the concepts of KL-One-like languages. Further language constructs allow the formulation of default and control knowledge. The inference engine for L_{LILOG} was designed as an experimental theorem prover, allowing us to investigate the behavior of various inference calculi as well as a number of search strategies. Processing with L_{LILOG} is not restricted to a propositional reasoner for logical formulas; we are also able to delegate special kinds of inferences to external deductive components. Currently, one such external reasoner for processing spatial information on the basis of analog representation is attached to the inference engine.

Unique design concepts in GF11 and their impact on performance *by M. Kumar, p. 990.* GF11 is a 512-way SIMD parallel computer currently used to verify quantum chromodynamics theory and to explore the SIMD approach to parallel processing. System design choices, such as network design, processing element design, and other architectural features, allow GF11 to sustain very high performance, close to the 10-gigaFLOPS peak. Several applications, such as structural analysis, seismic modeling, computational fluid dynamics, and linear algebra, have been ported to GF11. Applications execute in the range of 4 to 10 gigaFLOPS. The diversity in applications that perform well on GF11 demonstrates that the SIMD architecture is effective for a much larger set of applications than previously believed. The high network and data-memory bandwidths minimize the effort required to tune applications for optimum performance.

Architecture, design, and performance of Application System/400 (AS/400) multiprocessors *by J. E. Bahr, S. B. Levenstein, L. A. McMahon, T. J. Mullins, and A. H. Wottreng, p. 1001.* The architecture, design, and performance of multiprocessors in the Application System/400® (AS/400®) family are discussed. The paper describes how this multitasking system, originally designed as a uniprocessor system, was modified to form a multiprocessor system. The unique approach, using *relatively atomic instructions*, required a minimum of change while providing significant performance gains.

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Architecture and performance of the ESPER-2 hard-disk drive servo writer *by H. Ono, p. 3.* The servo writer is known as the most accurate and sensitive tool on an HDD (hard-disk drive) manufacturing line. ESPER-2 is designed as a product-independent common servo writer which incorporates major advances in equipment cost, reduction of clean-room requirements, and writing accuracy. The servo writing process consists of two stages. The first stage writes the master servo pattern on as many as ten disks at once with little need for contaminant protection facilities. One such master disk is then assembled with other, raw, disks in a file, and the second stage writes the proper servo pattern on all disk surfaces by referring to the master. The effects of off-center discursions in the mechanical disk assembly and random runout (NRRO, or nonrepeatable runout) in the product spindle components are eliminated by table-lookup servo actuator control, so that writing accuracy is improved. Neither an exceptionally clean environment nor fine mechanical parts are required for the second-stage operation.

Proof of correctness of high-performance 3–1 interlock collapsing ALUs *by J. E. Phillips and S. Vassiliadis, p. 12.* A 32-bit 3–1 interlock collapsing ALU, proposed to allow the execution of two interlocked ALU-type instructions in one machine cycle using an instruction-level parallel machine implementation, is shown to produce results equivalent to a serial execution of the instructions using a 2–1 ALU. The equivalence is shown by deriving tables which represent all possible requirements for the serial execution of the instructions followed by the generalization of the table to represent sets of instructions rather than the individual instructions themselves. Consequently, the equivalence of the 3–1 interlock collapsing ALU operations with these generalized requirements of the serial execution of the instructions is shown. The correctness of a proposed high-speed interlock collapsing ALU is thereby demonstrated.

Electrical characterization and performance limits of a flexible cable *by A. Deutsch, D. W. Dranchak, G. Arjavalingam, C. W. Surovic, J. K. Tam, G. V. Kopcsay, and J. B. Gillett, p. 22.* The electrical performance of a flexible-cable test structure is characterized from low frequencies up to 25 GHz. The experimental results are used to develop and refine models which describe the performance of such cables, with particular emphasis on the contribution of dielectric and resistive losses, including skin effect. The capability of triplate flexible cables to provide high-bandwidth connections over long lengths is investigated with the models developed. A triplate design is chosen because it offers high density, limited crosstalk, no loss through radiation, and relatively inexpensive fabrication. Bit rates of 100 Mb/s–1 Gb/s are considered for propagation over lengths up to 250 cm. The paper highlights the performance-limiting factors through realistic examples, including the contribution of interfaces to other interconnection structures.

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Preface *by J. Horkans, p. 83.*

***In situ* surface pH measurement during electrolysis using a rotating pH electrode** *by H. Deligianni and L. T. Romankiw, p. 85.* An *in situ* technique has been developed for measuring the surface pH adjacent to a solid electrode/liquid interface during electrolysis. Measurements of the surface pH can be used to obtain insights regarding the electrodeposition of various transition metals and to obtain a better understanding of associated *in situ* surface chemistry effects. Many transition metals and alloys deposit with simultaneous hydrogen evolution and, as a result, are accompanied by a pH rise near the cathode, thereby affecting the reactivity of the nearby metal-ion species. Measurements of the surface pH of a solution containing simple salts during hydrogen evolution from a cathode were performed. The surface pH of a cathode during Ni and NiFe electrodeposition was also measured. The experiments demonstrated that, in the absence of buffers or metal ions, the surface pH rises many pH units above the bulk value. During Ni and NiFe electrodeposition, however, the surface pH of solutions consisting of simple salts and starting from a bulk pH level of 2 does not increase more than 3 pH units from the bulk value. In the case of Ni and NiFe electrodeposition, surface buffering occurs because of the hydrolysis of the metal-ion species present. Additionally, it is found that during the anomalous codeposition of NiFe, the surface pH is much lower than that required by the Dahms–Croll hypothesis.

A rotating ring-disk stripping technique used to study electroplating of Sn–Pb from methane sulfonic acid solutions *by J. Horkans, I.-C. Hsu Chang, and P. C. Andricacos, p. 97.* A rotating ring-disk stripping technique has been used to analyze Sn–Pb alloys plated from methane sulfonic acid solutions with and without a proprietary additive and to construct associated current–potential curves. The deposition of both pure Sn and pure Pb was polarized by the additive, but the polarization was much greater for Pb. For alloys plated without the additive, the potential dependence of the partial currents i_{Sn} and i_{Pb} was essentially the same as that of the pure metals. The alloy compositions were very different from the solution ratios Sn(II):Pb(II) and could be either tin-rich or lead-rich compared to the solution. In the presence of the additive, on the other hand, the alloy compositions approximated the solution compositions of the metal ions; both Pb and Sn deposition were polarized in the alloy compared to deposition of the pure metals, but the extent of polarization caused by the codepositing metal was much greater for Sn. The electrodissolution of Sn–Pb alloys in HCl shows a complex oscillatory behavior, which is produced by the selective dissolution of Sn but which may also be sustained by the formation and redissolution of sparingly soluble surface films. The oscillatory behavior disappears at low dissolution current and low rotation rate, which favor a

higher surface concentration of the dissolving metals. Composition determinations are essentially the same under conditions with and without oscillations.

Mechanistic insights into metal-mediated electroless copper plating employing hypophosphite as a reducing agent *by J. G. Gaudiello and G. L. Ballard, p. 107.* Electroless copper plating using systems containing a small amount of Ni^{2+} or Pd^{2+} as a mediator and hypophosphite as a reducing agent was investigated using several electrochemical techniques. Isothermal and component-dependent polarization, rate, E_{mix}, split-cell, and ac impedance data suggested that the systems obey mixed potential theory and function as follows: a) the mediator is initially deposited from solution to the surface of the workpiece via hypophosphite reduction, b) oxidation of the hypophosphite at mediator sites supplies charge for Cu reduction, and c) Cu plating occurs over the entire workpiece. XPS analysis and depth profiling of the resulting deposits suggested that they are homogeneous in nature and that the mediator is uniformly distributed throughout. The chemical composition determined by the XPS analysis agrees well with the results obtained by atomic emission spectroscopy. In addition, the analysis showed no evidence of Cu oxide formation.

Electroless plating of copper at a low pH level *by R. Jagannathan and M. Krishnan, p. 117.* A new process for electroless copper plating at a pH level of ≤ 9 is described. The process uses amine borane reducing agents and ligands based on neutral tetradentate nitrogen donors. The use of a variety of buffer systems is demonstrated. Electroless bath performance over a wide range of conditions is presented. The quality of the plated copper is comparable to that obtained by currently used electroless plating processes, and has a resistivity of about 1.8–2 $\mu\Omega$-cm, depending on bath composition and process parameters. Use of the process is illustrated for forming conductors and filling via holes having submicron minimum dimensions.

Feature-scale simulation of resist-patterned electrodeposition *by J. O. Dukovic, p. 125.* A numerical simulation of resist-patterned or "through-mask" electroplating has been performed to investigate shape evolution at the scale of small lithographic features. Shape evolution and step coverage have a significant influence on the shapes of such microelectronic structures as conductor lines, vias, and magnetic pole pieces. The simulation and associated analysis are based on a model for the rate distribution of the electrodeposition reaction that includes the depletion of the depositing metal ions and the inhibiting action of leveling agents. A stagnant boundary layer is assumed to be present, and the diffusion theory of leveling with a one-parameter description of kinetic inhibition is employed. The results show that when the geometry of a feature cavity makes possible the occurrence of concentration-field effects (such as radial diffusion), an uneven metal-ion flux should cause nonuniform growth at high fractions of the limiting current, and leveling agents should exert an opposing effect, even causing a strong reverse nonuniformity in some cases.

Mass transfer of an impinging jet confined between parallel plates *by O. A. Moreno, R. H. Katyl, J. D. Jones, and P. A. Moschak, p. 143.* An understanding of the mass transfer behavior of an impinging jet can be usefully applied to wet chemical processes such as water rinsing, photoresist development, and metal etching or plating. Theoretical and experimental methods were used to study the mass transfer characteristics of an axisymmetric impinging jet confined between two parallel plates. Such a configuration was used because of its potential applicability to the fabrication of printed wiring boards. The CFD (computational fluid dynamics) method was used to model fluid flow and mass transfer. An electrochemical probe based on the ferro-ferricyanide system was used to experimentally determine the mass transfer coefficients and to evaluate the applicability of the theoretical methods used. An etching method was used to characterize the mass transfer rates in a typical cupric chloride etching solution. A new observation of the effect of jet instability on the etching rate in the central impingement zone is discussed.

The quartz resonator: Electrochemical applications *by K. K. Kanazawa and O. R. Melroy, p. 157.* Since the discovery that the oscillations of resonating quartz crystals can be sustained in a liquid environment, such crystals have quickly found use as a sensitive microbalance in electrochemistry, making possible *in situ* measurements of mass changes at the electrochemical interface. The early contributions of the IBM Almaden Research Center to this exciting field of development are sketched. The principles of operation are detailed, with emphasis on an intuitive description to permit considerations of new applications. Mass density changes of the order of 10 nanograms per square centimeter (ng/cm^2) are routinely detectable as changes in the resonant frequency of about a hertz. The mass density of a monolayer of material ranges from a few tens of ng/cm^2 for polymeric materials to a few hundreds of ng/cm^2 for metals. Detailed analysis of the electrical behavior of the resonator in liquid media shows that the resonant frequency, the quality factor of the resonance, and the admittance at resonance are all sensitive to the viscoelastic properties of the contacting liquid, having implications in the study of the behavior of non-Newtonian fluids, including polymeric films.

Corrosion and protection of thin-line conductors in VLSI structures *by V. Brusic, G. S. Frankel, C.-K. Hu, M. M. Plechaty, and G. C. Schwartz, p. 173.* Thin metallic lines in VLSI circuit structures are usually encapsulated in a dielectric in order to protect them from the atmosphere and prevent corrosion. However, during processing the lines are unprotected. Some of the steps to which they are subjected during processing are quite aggressive and can result in a significant yield loss. This paper pertains to the loss which is due to corrosion during processing. It focuses on the

corrosion behavior of the two of the most commonly used conductors, aluminum and copper. Aluminum alloyed with small amounts of copper is also considered. The corrosion-related behaviors of aluminum and copper are vastly different, as is shown by their reaction with water and several processing solutions. The challenge of minimizing corrosion during processing as well as during subsequent storage and use is discussed, using suitable examples drawn from studies of thin films of the metals exposed to chemical etching, reactive ion etching, and cleaning.

Application of X-ray spectroscopy to the study of electrochemically formed surface oxide films *by A. G. Schrott and G. S. Frankel, p. 191.* Many analytical techniques can provide information regarding the chemical state, structure, and properties of materials. This paper focuses on two; X-ray photoelectron spectroscopy (XPS) and X-ray absorption spectroscopy (XAS), and their application to the study of electrochemically formed oxide films. A brief review of the phenomena underlying these techniques is provided, along with a description of the commonly used means for implementing them. Their capabilities and limitations are discussed, with an emphasis on the study of passive film composition and oxidation state. A summary of the behavior of Cr in oxide films on Al–Cr alloys is presented as an example. The coordinated use of both XPS and XAS is shown to be useful in achieving full understanding of materials systems such as electrochemically formed oxide films.

Anodic dissolution of metals at high rates *by M. Datta, p. 207.* Electrochemical metal shaping and finishing processes involve anodic dissolution of metals at high rates. This paper presents a review of some fundamental aspects related to the understanding of such processes. Included are discussions of the phenomena of passive film breakdown that lead to the transpassive dissolution of metals, some of the available information on anodic reaction stoichiometry, and the role of convective mass transport and salt precipitation layers on metal removal rate and surface finish. The use of pulsating current permits the altering of anodic mass transport rates and transpassive dissolution behavior, thereby making it possible to obtain high dissolution efficiencies even at low average current densities.

***In situ* infrared spectroscopy of the electrode–electrolyte interface** *by H. Seki, p. 227.* In the study of electrochemical processes, it is important to have a means for characterizing the molecular and ionic species at the electrode–electrolyte interface. Various types of optical vibrational spectroscopy are being used to do this *in situ*. Of these, Fourier transform infrared reflection absorption spectroscopy (IRRAS) has seen rapid progress and is in wide use. A review of the techniques used in our laboratory and examples of recent measurements are presented. The adsorbed species discussed are CO, CN^-, SO_4^{2-}, and HSO_4^-, and the electrodes are, in most cases, polycrystalline noble metals. It is shown how the interpretation of the infrared spectra is greatly aided by comparison with *ab initio* molecular orbital computations of ions and molecules on metal clusters. Some of the difficulties in the interpretation of the infrared spectra are illustrated, and the future development of optical vibrational spectroscopy for studying electrode–electrolyte interfaces is discussed.

Conduction mechanisms in contaminant layers on printed circuit boards *by J. R. White, p. 243.* AC impedance methods have been utilized to explore surface conduction mechanisms on printed circuit boards (PCBs) containing various types of solder flux contaminants. Residues from water-soluble, rosin-based, and no-clean fluxes were analyzed and evaluated for their potential impact on reliability. Impedance data for intentionally contaminated PCBs having several circuit line geometries were obtained at different relative humidities. An equivalent circuit model is presented that fits the data obtained. It is used to evaluate and distinguish among ohmic, kinetic, and diffusion effects and to predict the environmental conditions that may be detrimental for various line geometries.

Contact charging of organic materials: Ion vs. electron transfer *by A. F. Diaz and J. Guay, p. 249.* In this paper we describe some of the recent literature on the contact charging (also known as tribocharging and contact electrification) of organic materials. Although it is a very familiar phenomenon, much remains to be understood about the mechanism of charging with organic materials. It has been proposed that the charging is due to the transfer of electrons and/or ions. In some studies, the correlation between the charging and the substituent constants for a substituted series of compounds has been used to support the electron transfer mechanism, and it has been proposed that the correlation reflects systematic changes in the energy levels of the highest and lowest occupied molecular orbitals of the derivatives. In others, the detection of the ions that are transferred during contact and the correspondence between their sign and that of the transferred charge have been used to support the ion transfer mechanism. In this paper, we discuss a selected number of papers that relate the charging behavior to electrochemistry and discuss the results reported in light of the two transfer mechanisms.

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Preface *by J. M. Warlaumont, p. 288.*

Early history of X-ray lithography at IBM *by E. Spiller, p. 291.* We present a reconstruction of the early work on X-ray lithography at the IBM East Fishkill facility in 1969 and 1970 and a summary of the efforts at the Thomas J. Watson Research Center in Yorktown Heights, New York, between 1973 and 1976.

X-ray lithography in IBM, 1980–1992, the development years *by A. D. Wilson, p. 299.* The IBM X-ray lithography research and development program is outlined, from a

personal perspective, covering the period from the inception of the program in 1980 through the development of IBM's own storage ring for X-ray production in 1992. The following aspects, among others, are discussed: origins of the program; acquisition of an X-ray port at Brookhaven National Laboratory; masks for X-ray lithography; development of special tooling for X-ray lithography, including a wafer stepper, a precision e-beam X-ray mask writing system, and a superconducting (dipole) electron synchrotron installed in the IBM Advanced Lithography Facility (ALF) in East Fishkill, New York. Key device programs were conducted to increase understanding of the X-ray lithography process and confirm its utility.

X-ray lithography from 500 to 30 nm: X-ray nanolithography *by H. I. Smith and M. L. Schattenburg, p. 319.* Proximity X-ray lithography (XRL), using wavelengths between 0.8 and 1.5 nm, provides a near-ideal match to the "system problem" of lithography for feature sizes from 500 to 30 nm, by virtue of "absorption without scattering" and recently developed mask technology. The effects of photoelectrons, at one time thought to be problematic, are now understood not to limit resolution. With experiments and simulations via Maxwell's equations, we show that useful resolution is not limited by diffraction until linewidths are below 50 nm. It is critically important to optimize the source spatial incoherence to eliminate the deleterious effects of high spatial frequencies. Mask architecture and patterning methods are presented which we believe are compatible with manufacturing at linewidths from 500 to 30 nm. Distortion due to mask frame flexing and absorber stress can now be eliminated. Elimination of distortion at the pattern generation stage remains the problem of greatest concern. We discuss a proposed method of spatial-phase-locked electron-beam lithography which could solve this problem. Our new interferometric alignment scheme has achieved 18-nm alignment at 3σ. We assert that projection XRL using multilayer mirrors at 13 nm can never match the present performance of proximity XRL. Applications of sub-100-nm XRL, including MOS, quantum-effect, and optoelectronic devices are discussed which illustrate the benefits of high resolution, process robustness, low distortion, low damage, and high throughput.

Modeling X-ray proximity lithography *by J. Z. Y. Guo and F. Cerrina, p. 331.* Advanced semiconductor circuits, such as DRAMs, are based on very complex fabrication processes. Because of the cost and complexity involved, it is rapidly becoming impossible to adopt a "trial-and-error" approach in the development stage of a new process. Fortunately, the advances in computer power spurred by the new semiconductor devices have made it possible to compute the response of complex systems in a reasonable time on workstations. Thus, the study of a virtual representation of the process (that is, a model) can represent a solution to the high cost of process development—of course, after verification of the model accuracy through controlled experiments. A correct physical interpretation of the process under study is necessary in order to implement a model that is both accurate and extendible. This is particularly true for new approaches, such as those involved in X-ray lithography. We have studied the process of image formation in X-ray lithography and have implemented several models to predict the intensity distribution at the wafer plane. The models can be applied to the definition of an optimal exposure system that will provide the maximum exposure latitude, and to the study of new types of X-ray masks.

The Helios 1 compact superconducting storage ring X-ray source *by M. N. Wilson, A. I. C. Smith, V. C. Kempson, M. C. Townsend, J. C. Schouten, R. J. Anderson, A. R. Jorden, V. P. Suller, and M. W. Poole, p. 351.* The basic properties of synchrotron radiation are described, the design of storage rings to produce synchrotron radiation is outlined, and the criteria for matching storage ring design to the needs of X-ray lithography are discussed. Simple scaling laws are presented showing the benefits for a storage ring of using the higher fields which superconducting magnets are able to provide. Helios 1 is a compact superconducting storage ring built by Oxford Instruments for installation at the IBM Advanced Lithography Facility (ALF). Design choices for superconducting rings are discussed, and the design and construction of Helios are described. Test results from the initial commissioning of Helios at Oxford are presented, but the main data on its performance when installed at ALF are given in another paper in this issue.

Performance of the IBM synchrotron X-ray source for lithography *by C. Archie, p. 373.* The compact superconducting synchrotron X-ray source at the IBM Advanced Lithography Facility in East Fishkill, New York has been in service to customers since the start of 1992. Its availability during scheduled time is greater than 90%, with recent months frequently surpassing 95%. Data on the long-term behavior of the X-ray source properties and subsystem performance are now available. The full system continues to meet all specifications and even to surpass them in key areas. Measured electron beam properties such as beam size, short- and long-term positional stability, and beam lifetime are presented. Lifetimes greater than 20 hours for typical stored beams have significantly simplified operations and increased availability compared to projections. This paper also describes some unique features of this X-ray source and goes beyond a discussion of downtime to describe the efforts *behind the scenes* to maintain and operate it.

Design considerations for the IBM X-ray lithography facility *by J. A. Leavey and L. G. Lesoine, p. 385.* Synchrotrons, like other large particle accelerators, have historically been the tools of universities and national laboratories for research. Moving this technology to industry presents many challenges which do not exist in an academic environment. One major challenge is to develop a facility to house and support the ring in a manufacturing-like mode

where operator, customer, and public concern for radiation and industrial safety is of extreme importance. This paper describes IBM's efforts to design and build a facility to address these safety concerns.

X-ray lithography beamlines in the IBM Advanced Lithography Facility *by J. P. Silverman, R. P. Rippstein, and J. M. Oberschmidt, p. 395.* In 1991 a storage ring designed as a source of X-rays for X-ray lithography was delivered, installed, and commissioned in the IBM Advanced Lithography Facility (ALF) in East Fishkill, New York. Beamlines of two different designs have been constructed and installed on the ring to deliver the X-rays to the exposure stations. One design is intended for use with a stepper for the fabrication of integrated circuits. The second design is for a general-purpose research and development beamline which is used for unaligned exposures as well as for characterization of beamline components. The design and performance of both are described. Special attention is given to a paraboloid mirror optical system which is used to collimate the radiation from the storage ring. Both the theoretical and the measured performance of the mirror are presented and shown to be in excellent agreement. An exposure nonuniformity of less than ±3%, including contributions from both the mirror and the beryllium exit window, has been achieved.

Electron beam lithography tool for manufacture of X-ray masks *by T. R. Groves, J. G. Hartley, H. C. Pfeiffer, D. Puisto, and D. K. Bailey, p. 411.* An electron beam lithography system suitable for manufacturing X-ray masks with critical dimensions down to 0.35 μm is described. The system features a 50-kV variable shaped spot (VSS) electron column with a variable axis immersion lens (VAIL). This column is capable of maintaining 0.035-μm edge acuity of the focused spot over a 2.1-mm deflection field. These fields are stitched together over an 84 × 84-mm active pattern area via motion of an *xy* table. The table position is measured using a laser interferometer. The measurement data are fed back to the magnetic deflection to correct small errors. Maintaining positional accuracy of the beam relative to the writing surface relies on a strategy of measuring and correcting repeatable errors. This is described in detail. Pattern placement accuracy is 0.070 μm (3σ) and image size control is 0.025 μm (3σ), achieved over the entire 84 × 84-mm pattern area. This performance is achieved with yield better than 90%, as confirmed by routine measurements. The system is currently used to manufacture product X-ray masks with 0.35-μm critical dimensions. Typical measurement results on product masks are presented.

X-ray mask repair *by P. G. Blauner and J. Mauer, p. 421.* A method for repairing X-ray lithographic masks using focused ion beam technology is described and demonstrated. The ion beam is used for mask imaging, for absorber milling for opaque repair, and for deposition of X-ray-opaque material for clear repair. Solutions to the unique problems faced in executing these tasks on the high-resolution, high-aspect-ratio patterns characteristic of X-ray masks are discussed. Several effects of material redeposition during opaque repair are explored. The significance of this same redeposition during clear repair and the resulting advantage gained in using a high-yield deposition process are illustrated. Examples of repairs and printed images of these repairs are shown for feature sizes smaller than 0.25 μm.

Resist materials and processes for X-ray lithography *by D. Seeger, p. 435.* A key component that is sometimes overlooked in X-ray lithography is the resist material. The lithographic properties of these materials are extremely important if one is to take advantage of the superior lithographic performance often observed in X-ray lithography. The properties of such materials may even be more important than in conventional optical lithography, since the feature sizes delineated by this lithographic technique are much smaller. A description of X-ray resists is presented which discusses both the chemistry and the lithographic properties of these materials. The characterization and stability of these processes are highlighted.

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Head actuator dynamics of an IBM 5 1/4-inch disk drive *by D. P. Fazzio, M. A. Moser, C. J. Polson, and J. N. Scheffel, p. 479.* The IBM 5¼-inch disk drive contained in the IBM 9345 DASD Module provides high track density and storage capacity, dynamic test failure rates below three parts per million, and low sensitivity to assembly variations. The design techniques used to achieve the required vibrational characteristics of the head actuator assembly are described. Dynamic stability specifications are derived from drive performance requirements and the actuator servomechanical system design. Modeshapes of the actuator are determined by encoding magnetic patterns onto a disk and using the read/write heads as position transducers in an operational drive. Structural changes in the carriage assembly that might lead to design improvements are explored with models derived using finite element analysis. Taguchi orthogonal matrix experiments are used to reduce the sensitivity of the actuator to dimensional tolerances and assembly processes. The achievement of actuator assembly design objectives is verified from production yields and statistical data obtained during dynamic tests.

Statistical modeling in manufacturing: Adapting a diagnostic tool to real-time applications *by B. E. Osborn, p. 491.* This paper describes a process for constructing a statistical model to automate the analysis of data from complex diagnostic tools. The method is demonstrated on data taken from an optical emission spectrometer (OES), one of the most powerful tools used in semiconductor manufacturing for detecting the chemical composition and impurity levels in plasma processes. The analysis of OES data currently requires hours of manual effort by an expert spectroscopist, rendering it ineffective for real-time

monitoring and control. However, through the use of statistical modeling, the analysis can be performed automatically on a personal computer in a matter of seconds. The process of model construction is examined in general, and methods are developed for demonstrating how information from an expert can be combined with information from the data in order to provide a statistical basis for analysis. The effectiveness of the model is demonstrated on data from typical plasma processes.

Flexible simulation of a complex semiconductor manufacturing line using a rule-based system *by B. R. Tibbitts, p. 507.* Rule-based systems have been used to produce fast, flexible simulation models for semiconductor manufacturing lines. This paper describes such a rule-based simulator for a semiconductor manufacturing line, and the language in which it is written. The simulator is written in a rule-based declarative style that uses a single-rule "template" to move thousands of product lots through various process steps; the rule is customized as needed with data for each step, route, lot, tool, manpower skill, etc. Since line or product changes require only reading new data from a database, without reprogramming, this provides a modeling environment that is simple, flexible, and maintainable. The model is implemented in ECLPS (Enhanced Common Lisp Production System), also known as a knowledge-based or expert systems language. It handles very large models (thousands of data elements, or more) well and is very fast. Subsequent changes improved the speed several orders of magnitude over that of an older version of the model, primarily through use of a preprocessor to eliminate duplicate and redundant data, and by enforcing data typing to take advantage of special techniques for very fast processing of extremely large matches (hashed indices). ECLPS also provides a built-in simulated time clock and other constructs to simplify simulation applications. The model runs daily at the IBM semiconductor manufacturing plant in Yasu, Japan, where it has been in use for many years, currently on three different semiconductor manufacturing lines.

Component procurement and allocation for products assembled to forecast: Risk-pooling effects *by S. J. Grotzinger, R. Srinivasan, R. Akella, and S. Bollapragada, p. 523.* This paper considers procurement and allocation policies in a manufacturing environment where common components are assembled into various products that have stochastic demands. The components are allocated to the assembly of a product at a time when product demand is still uncertain (assemble to forecast, ATF). The special case of one component shared by N different products is analyzed, and insights into the general problem are obtained for the situation in which the common component can be reallocated to different products as product demands change. An allocation policy is developed for general distributions and prices in an ATF environment. The policy first addresses anomalies in the state of the system and then, for a feasible state, minimizes the expected excess finished-goods inventory. A procurement level that is nearly optimal is obtained from a Monte Carlo simulation in which the probability of satisfying all of the random product demands simultaneously is considered relative to this allocation policy. Numerical studies indicate that the total component and finished-goods inventory is significantly reduced by an allocation policy that incorporates risk pooling while still fulfilling service-level requirements.

Modeling the cost of data communication for multi-node computer networks operating in the United States *by D. R. Irvin, p. 537.* The study reported here examines the cost of data communication for multi-node computer networks operating in the United States. We begin by defining a market basket of private-line transmission services and identifying its constituent prices. Two analytic models are then proposed. The first, which derives a theoretical relationship from microeconomic considerations, gives price movement as a function of the demand for service. The second embodies a learning curve fit to historical data, wherein the slope of this curve (0.71) equals the slope of the historical curve for the advance of integrated-circuit technology. Extrapolations from the two models agree well; moreover, both extrapolations conform to long-established historical trends. These agreements lend plausibility to the idea that the price of data communication unfolds in an orderly way over the long run, and, despite the perturbation introduced by the Bell System divestiture of 1984, future price movements may return to their traditional 11% annual decline.

A load-instruction unit for pipelined processors *by R. J. Eickemeyer and S. Vassiliadis, p. 547.* A special-purpose load unit is proposed as part of a processor design. The unit prefetches data from the cache by predicting the address of the data fetch in advance. This prefetch allows the cache access to take place early, in an otherwise unused cache cycle, eliminating one cycle from the load instruction. The prediction also allows the cache to prefetch data if they are not already in the cache. The cache-miss handling can be overlapped with other instruction execution. It is shown, using trace-driven simulations, that the proposed mechanism, when incorporated in a design, may contribute to a significant increase in processor performance. The paper also compares different prediction methods and describes a hardware implementation for the load unit.

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Preface *by C. K. Lim, T. Caulfield, and J. Benenati, p. 582.*

Finite element analysis for Solder Ball Connect (SBC) structural design optimization *by J. S. Corbin, p. 585.* Solder Ball Connect (SBC) is a second-level surface mount electronics packaging technology in which ceramic modules containing one or more chips are joined to a circuit card (FR-4) by means of an array of nonhomogeneous solder columns. These columns consist of a high-temperature-melting 90%Pb/10%Sn solder sphere

attached to the module and card with eutectic solder fillets. The solder structures accommodate the bulk of the strain (which is due to the thermal-expansion mismatch between FR-4 and the 9211 ceramic of the modules) generated during power cycling. If the solder structures are not properly designed, the thermal strain can be a source of premature fatigue failure. In this work, finite element analysis is used to characterize the plastic strains that develop in the SBC interconnection during thermal cycling. Since plastic strain is a dominant parameter that influences low-cycle fatigue, it is used as a basis of comparison for various structural alternatives. Designed experiment techniques are used to systematically evaluate the thermal strain sensitivity to structural variables. Results are used to identify an optimally reliable structure that is robust in terms of assembly-process variables.

Attachment of Solder Ball Connect (SBC) packages to circuit cards *by M. D. Ries, D. R. Banks, D. P. Watson, and K. G. Hoebener, p. 597.* IBM has developed an assembly process to attach a new family of Solder Ball Connect (SBC) integrated circuit packages to glass/epoxy cards using surface mount technology (SMT). The process provides nearly perfect yields for the resulting solder ball joint structures and ensures reliability by controlling wear-out due to metallurgical fatigue. The package, card, and process parameters found to most strongly influence the assembly yield and reliability are summarized, and unique test hardware and analysis techniques are discussed. Process considerations, analytical techniques, and test methods described for SBC packages should apply to other ball grid array (BGA) packages.

Thermal modeling of the infrared reflow process for Solder Ball Connect (SBC) *by H. V. Mahaney, p. 609.* A thermal model of the infrared reflow process has been developed for an FR-4 card populated with an array of Solder Ball Connect (SBC) modules. The analysis of the three-dimensional, transient, finite element model accounts for radiative exchange within the infrared oven and for the heat conduction (nonisotropic) within the modules and card. Transient temperature profiles of selected points and three-dimensional temperature distributions at selected times are presented to describe the primary heat-transport mechanisms. Numerical predictions and empirical data indicate that the SBC modules are relatively isothermal throughout the infrared reflow process. Therefore, every solder ball within the array exhibits a nearly identical thermal profile. This result is fortunate, since the inner solder ball connections cannot be visually inspected. The influence of module spacing and the ability to improve the reflow process by use of a high-emissivity cap coating are demonstrated.

Thermal–mechanical strain characterization for printed wiring boards *by T. Y. Wu, Y. Guo, and W. T. Chen, p. 621.* Multilayer printed wiring boards are widely used in electronic packaging assemblies. One critical reliability concern is the thermal–mechanical strains induced by temperature change. For example, the in-plane strain affects the thermal fatigue life of surface mount solder interconnections, while the out-of-plane strain affects the mechanical integrity of the plated-through holes of the printed wiring boards. For this paper, a systematic study of the thermal–mechanical strain of epoxy–glass printed wiring boards, below and above the glass transition temperatures of the epoxies, has been carried out. The study includes measurements of properties of basic constituent materials (epoxy, glass fabric, copper), of intermediate building blocks in the fabrication process, and of final products. The study has led to a quantitative engineering model that predicts the average in-plane thermal–mechanical strain for use in modeling surface mount components on a printed wiring board, as well as the average out-of-plane thermal–mechanical strain for determining plated-through-hole reliability in thermal shock processes. The model was verified by two experimental techniques (measurement by thermomechanical analyzer, and moiré interferometry) applied to two epoxy resins and three glass fabrics, with and without copper planes. For thermal shock below the glass transition temperatures of the epoxy resins, the in-plane and out-of-plane strains are described by a modified rule-of-mixtures theory and a biaxial plane stress model, respectively. For temperatures above the glass transition temperatures, the in-plane strains are governed by the copper and glass fabric, whereas the out-of-plane strains are dominated by the incompressible fluid behavior of the epoxy resins. The nonuniform pattern of thermal expansion in regions populated with plated-through holes was examined. The reliability of surface mount solder interconnections and plated-through holes is discussed.

Solder Ball Connect (SBC) assemblies under thermal loading: I. Deformation measurement via moiré interferometry, and its interpretation *by Y. Guo, C. K. Lim, W. T. Chen, and C. G. Woychik, p. 635.* Thermal deformations that result from mismatches of coefficients of thermal expansion (CTE) in Solder Ball Connect (SBC) assemblies were investigated. The CTE mismatches of the materials and the components in the package have both macro and micro effects on the strain distributions in the SBC interconnections. The geometry of the SBC joint also has a strong influence on the solder strains in the SBC package. An experimental technique with high sensitivity and resolution, moiré interferometry, was used to obtain whole-field displacements. Thermal strains in SBC packages, especially the strain concentrations in the SBC joints, were then determined from the displacement fields. The experimental results played an important role in failure analysis, structural design optimization, and finite element model verification in the IBM SBC program. The results also show that moiré interferometry is a very powerful and effective tool in experimental studies of electronic packaging.

Solder Ball Connect (SBC) assemblies under thermal loading: II. Strain analysis via image processing, and reliability considerations *by H.-C. Choi, Y. Guo, W.*

LaFontaine, and C. K. Lim, p. 649. A novel approach to processing interferometric moiré images, called computational Fourier transform moiré, has been developed. The essential principle of this technique is to automatically calculate a whole-field strain from digitized images of interferometric moiré fringes using digital Fourier transform procedures. With the use of this technique, a whole-field strain distribution of a Solder Ball Connect (SBC) interconnection under thermal loading was obtained. The calculated strain field was then used to understand fatigue modes of SBC observed from an accelerated thermal cycling (ATC) test.